

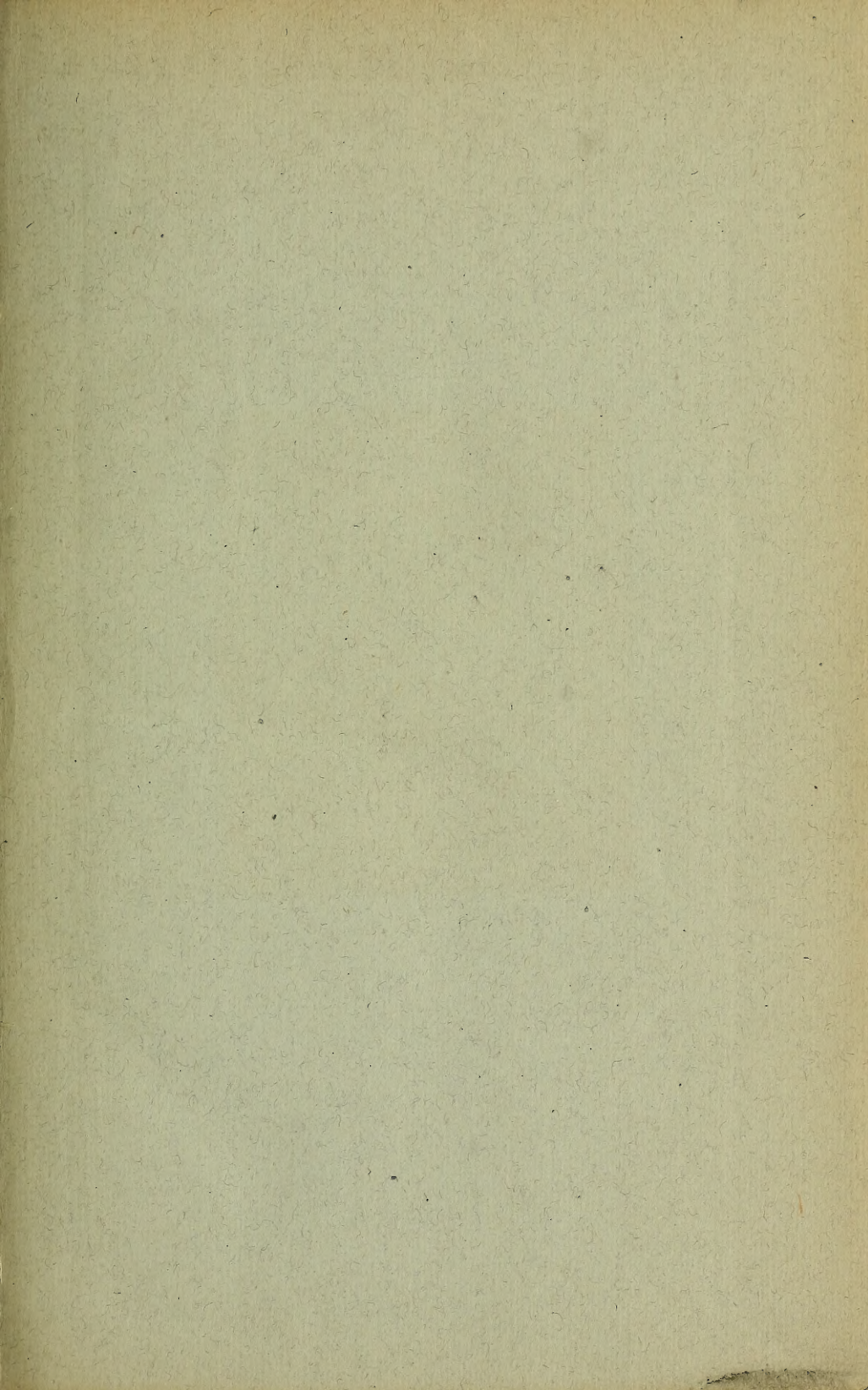
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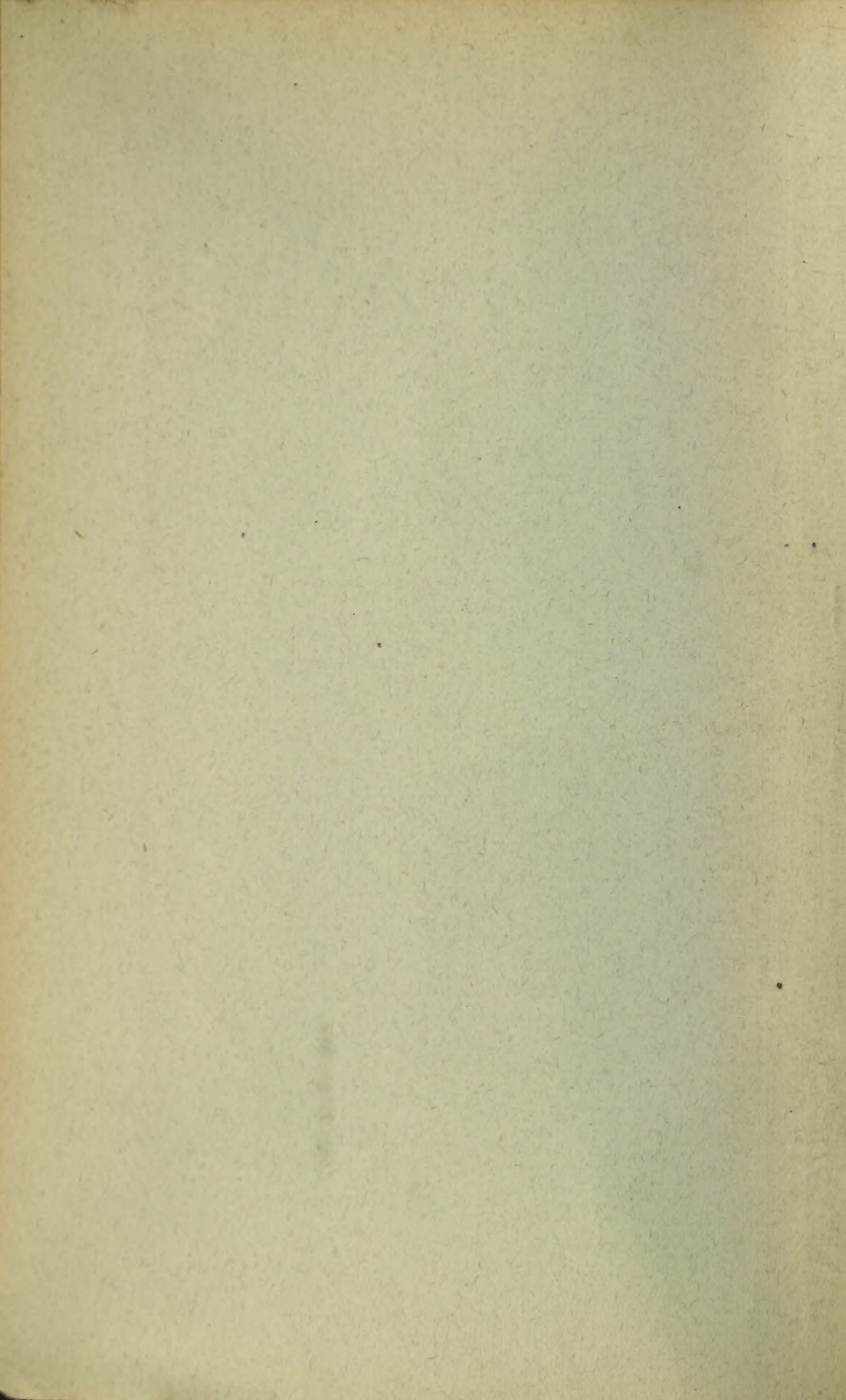
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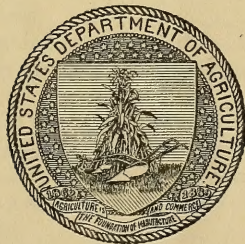
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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 76



Contribution from the Bureau of Animal Industry, A. D. Melvin, Chief.
April 29, 1914.

(PROFESSIONAL PAPER.)

LABORATORY AND FIELD ASSAY OF ARSENICAL DIPPING FLUIDS.¹

By ROBERT M. CHAPIN,
Senior Biochemist, Biochemic Division.

INTRODUCTION.

The use of arsenical dipping fluids for the treatment of cattle infested with Texas-fever ticks is increasing. A mixture termed by the Bureau of Animal Industry "standard arsenical solution" is prepared from white arsenic, sal soda, and pine tar, and is largely used for both official and private dipping operations. Proprietary dipping fluids also have appeared on the market to some extent. Previous publications² of the bureau contain directions for the preparation of "standard arsenical solution," together with general information of importance to users of arsenical dips.

During the last few years wide practical experience of the bureau with all kinds of arsenical dips in the field has shown with increasing forcefulness that one of the greatest obstacles to the successful use of these preparations, and consequently to the effective prosecution of the tick-eradication work now progressing so well over considerable areas, lies in the uncertainty attached in many cases to the composition of these dips. There is no doubt that arsenical baths, properly prepared and used, are very effective tickicides and cause little injury to cattle. But the Texas-fever tick is a resistant organism. Destruction only follows its immersion in rather strong solutions of arsenious oxid, so strong in fact that if made only a little stronger the cattle themselves will begin to show effects. That is, the margin of safety within which solutions of this violent poison may be satisfactorily used is rather narrow. Too little fails to kill the ticks; too much injures the cattle. In either case the cause of tick eradication

¹ A popular account of laboratory tests for actual arsenious oxid and for total arsenic, together with methods of field assay for dips used in tick eradication. Of special application to officials and others concerned with the analysis and control of these preparations.

² Farmers' Bulletin 498; Bureau Animal Industry Circular 207.

receives a setback, not only through the wasted labor of ineffective dippings or the economic loss of injured cattle, but still more through the arousing of distrust or even enmity in those very persons whose willing cooperation in tick-eradication work is most to be desired.

The causes which may lead to the use of a bath of the wrong strength are rather numerous. Impure materials may be purchased; mistakes in measurements or computations are sometimes made even by a careful man. But these things can all be checked and guarded against; the greatest difficulties arise in maintaining the bath at the right strength, once it has been prepared. A fresh bath can not be made up every time a few cattle are to be dipped. Practical considerations render it necessary to use the bath over and over again, perhaps during a period of several months, sufficient fresh fluid being added from time to time to replace that carried out by the cattle. During such a period of time, especially in the hot summer weather, evaporation of water from the dip naturally tends to concentrate it. This may be compensated for in a measure by marking the level of the dip on the side of the vat before a period of disuse, and then filling up to the mark with water when the dip is used again. But it is difficult to construct a vat holding one to three thousand gallons so as to be entirely free from leaks. Therefore it is uncertain in any case how much of the lowering of the level of the dip is attributable to evaporation and how much to leakage. Leakage may likewise be in as well as out; that is, rain, surface water, or ground water may enter the vat.

Even if these difficulties are avoided, there is still another factor which evades all precautions, the fact that used arsenical dipping fluids may in course of time undergo a process of oxidation whereby the arsenious oxid originally present as sodium arsenite is converted to arsenic acid or sodium arsenate. Various observers have noted such a tendency, but have usually attached little importance thereto, assuming it to be caused by a slow and relatively insignificant chemical reaction. It has remained for Fuller,¹ working in this laboratory, to show that the change is essentially caused by the growth of microorganisms in the fluid—that is, it is a biological process and not a simple chemical action—and furthermore that it may become very extensive, converting nearly all the arsenic into the oxidized form. Tests by the Zoological Division of the bureau indicate that arsenic in the form of arsenate is probably a less effective tickicide than when present as arsenite, while at the same time decidedly poisonous to animals. Laws,² as the result of a certain number of experiments, has concluded that arsenic existing as arse-

¹ Bureau Animal Industry Circular 182.

² Laws. The Tick-killing Properties of Sodium Arsenate. The Agricultural Journal of the Union of South Africa, 1913, vol. 5, p. 915.

nate is probably somewhat less than half as powerful as arsenic in the form of arsenite in its effects upon both cattle and ticks. Also it has recently been observed that arsenical baths under certain conditions sometimes display the converse phenomenon of reduction—that is, arsenate tends to be reconverted to arsenite. Laws, in the article above mentioned, suggests that the phenomenon of reduction may likewise be attributable to the action of microorganisms, of course of different species from the organisms which cause oxidation. Recent work in this laboratory has substantiated the correctness of Laws's surmise. Pending the completion of certain researches it may simply be stated here that both phenomena have been observed to occur in baths in actual use in the field, sometimes in the same bath; that is, a single bath may show alternating tendencies in the two directions, first toward oxidation, then toward reduction followed by oxidation again, and so on. The primary condition which determines in which direction the change shall progress at any given time or in any particular bath is the degree of use which the bath is receiving. Under present ordinary conditions which appear to prevail in the field a gradual oxidation may be looked for. It is only in vats through which cattle are passed in exceptionally large numbers and at very frequent intervals, such as the vats at some of the stockyards centers, that reduction as a separate phenomenon becomes apparent.

A consideration of the above facts renders sufficiently obvious the necessity for some analytical control of the baths used for dipping.

The assay of arsenical dipping fluids, at least with sufficient accuracy for practical purposes, is not a difficult matter. It is nowhere described in chemical literature, however, and the average chemist, when offered the problem, will be somewhat daunted, not knowing how he may best set to work to obtain good results without a considerable expenditure of labor. It is believed that some of the methods herein to be described can be successfully executed by persons who possess but a limited chemical training. In almost every section of the country there should be some one, pharmacist, physician, veterinarian, instructor in school or college, or even student, who would find it worth while for a comparatively small fee (provided a sufficient number of samples are sent in from various sources) to undertake the assay of such preparations. A 4-ounce sample¹ is sufficient, though a larger quantity is rather more convenient for the analyst.

It is also purposed to describe a portable testing outfit that has been devised for the use of bureau inspectors in the field, and that enables them, without the possession of any chemical knowledge whatever, at the side of the vat and in a few minutes, to determine

¹ For precautions necessary in sending samples see page 4.

the strength of arsenical solutions prepared after the "standard formula."

It is necessary therefore to describe (1) methods for the determination of actual arsenious oxid, and (2) methods for the determination of "total arsenic," that is, methods which shall include arsenic present in the oxidized form as well as that existing as actual arsenious oxid. It is necessary also to describe different variations or modifications of processes for these two determinations, respectively appropriate for use by (1) trained chemists with abundant laboratory facilities, (2) persons possessing but slight chemical training and equipment, and (3) persons in the field possessing no chemical knowledge or training whatever, who obtain their results by manipulation of an "outfit" prepared by a trained chemist.

LABORATORY METHODS.

It is to be distinctly understood that the methods here described are not in all cases adapted or intended to reach a high degree of accuracy from a chemist's viewpoint, though as a matter of fact most of them are very accurate under especially favorable conditions. A certain variation must necessarily be allowed in the composition of baths prepared in the field. Again, experience has shown that the percentage of arsenic in such baths may vary within certain limits without perceptible effect upon either their effectiveness or their safety. Therefore the purpose of assay is not primarily to determine the exact percentage of arsenic—though the nearer this result is approached the better—but to insure that the composition of the baths used shall fall within certain limits. Extreme accuracy, which is not necessary, must be sacrificed to simplicity and convenience, which are necessary to permit the execution of very frequent tests.

METHODS FOR ACTUAL ARSENIOS OXID.

Whatever method may be employed for the determination of actual arsenious oxid, there are certain precautions connected with the taking and the storage of samples which can not be omitted if the results are to be of any value whatever. As already noted, the arsenic in used arsenical baths tends to change its degree of oxidation, mainly through the action of microorganisms. Other things being equal, the rapidity with which this change takes place is greatly influenced by temperature, so much so that a sample contained in an ordinary cork-stoppered bottle and exposed to summer heat may show more change after one day than it would show after a week in the original vat in its comparatively cool location underground. The rate of the change can accordingly be retarded by keeping the sample cold, as by storage in an ice box after receipt; but if the sample has trav-

eled any considerable distance the mischief probably has already been done before its receipt. The growth of microorganisms, and consequently the change in degree of oxidation, can be inhibited by the addition of an appropriate antiseptic, such as formaldehyde, carefully added from a medicine dropper, in the proportion of 5 drops of the commercial 37 per cent solution to each 100 c. c. of bath. Carbolic acid and mercuric chlorid are wholly inappropriate for the purpose. Also since oxidation obviously can not take place in the absence of air, it is best to fill the bottle nearly full with the sample, leaving only a little air space, cork, and cover the cork and lip of bottle (which must be dry) completely with melted sealing wax, paraffin, rosin, or some similar material. Whatever means are employed to preserve the sample the operations ought to be executed at the vat side immediately after taking the sample. A few matches will furnish the heat necessary for melting the sealing material.

No sample should, of course, be taken from a vat until the contents of the latter have been thoroughly stirred up. Aside from general reasons for this practice in all sampling it is entirely possible that the oxidation of an arsenical bath standing at rest in the vat may proceed from the surface downward. That is, the upper few inches in free contact with air might have become almost entirely oxidized while toward the bottom the bath might be still in its original condition, or might even be undergoing reduction.

The first step for the analyst, therefore, is to determine whether the sample has been properly taken and properly preserved during shipment. If the necessary precautions have not been observed, the analyst is justified in reporting only a "probable" or "provisional" figure for "actual arsenious oxid."

The final measurement of arsenic is made in all cases by titration with standard iodine solution and starch indicator, much used by chemists for a variety of purposes. The necessary solutions are the following:

(1) *Starch solution*.—Stir up about a gram of starch, best obtained from the druggist, in about 20 c. c. of water and add the mixture slowly to about 200 c. c. of boiling water. Continue gentle boiling about 5 minutes. The solution should be freshly prepared every day.

(2) *Diluted sulphuric acid (10 per cent)*.—Pour 100 grams (or 55 c. c.) of concentrated sulphuric acid *slowly, in a small stream and with constant stirring*, into 825 c. c. of water.

(3) *Standard solution of arsenious oxid*.—Weigh out accurately and exactly 2.5 grams of the purest obtainable white arsenic, and about 10 grams of sodium bicarbonate, bring into a capacious beaker or flask with about 200 c. c. of water, and boil gently until the arsenic is all dissolved. Cool, and cautiously add dilute hydrochloric or

sulphuric acid until the solution is slightly acid to litmus paper or methyl orange, or, best of all, phenolphthalein. When thoroughly cooled to room temperature, make up the solution to exactly 1,000 c. c. Each cubic centimeter will then contain 0.0025 gram arsenious oxid. The chemist¹ will recognize this as approximately a "twentieth-normal" solution. If well stoppered, the solution will keep a year or more.

(4) *Standard iodine solution.*—Weigh out about 6.5 grams of iodine and 20 grams of potassium iodide. Cover with about 100 c. c. of water and leave, occasionally mixing, until all iodine is dissolved. Then make up to 1 liter. To obtain the exact strength of the iodine solution, measure exactly 25 c. c. of the standard arsenious oxid solution into a 200 c. c. flask or wide-mouth bottle, add about 25 c. c. of water, about 2 grams of sodium bicarbonate, and a few cubic centimeters of starch solution. Then, while shaking the flask, run in the solution of iodine from a burette² until the blue color of iodized starch just remains permanent. Twenty-five cubic centimeters of the standard arsenious oxid solution contain exactly 0.0625 gram of arsenious oxid. Therefore, the number 0.0625 divided by the number of cubic centimeters of iodine solution necessary to just produce a permanent blue color, gives a quotient which represents the exact weight of arsenious oxid to which each cubic centimeter of iodine solution is equivalent. For example, suppose 26.2 c. c. of iodine to be required. Then $0.0625 \div 26.2 = 0.00239$ gram arsenious oxid per each cubic centimeter of iodine. The standard iodine solution should be kept only in glass-stoppered bottles, as it will be weakened by contact with rubber or cork. If preserved in tightly stoppered and well-filled bottles in a cool, dark place, it retains its strength a considerable time, but in practice it should be standardized against the standard solution of arsenious oxid every week or two.

For the actual analysis two methods will be described. If the sample is a concentrated preparation, it should always be reduced by dilution with water to the strength at which it is intended for use in actual dipping.

METHOD "A" FOR ACTUAL ARSENIOS OXID.

Measure 25 c. c. of bath into a beaker, flask, or bottle of convenient size, add about a gram of sodium bicarbonate and about 10 c. c. of starch solution. Run in standard iodine solution until the blue color appears just as in standardizing the iodine solution, though here it

¹ The experienced chemist will undoubtedly employ solutions of definite normality. The directions here given are intended, as simply as possible, to meet the needs of those who may be without much chemical knowledge or a highly accurate analytical balance, perhaps lacking even burettes and pipettes.

² A 25 c. c. measuring cylinder may be employed if a burette is lacking.

usually fades out in a minute. In the case of very dirty baths the color may appear simply as a violet, reddish, or brownish deepening of the naturally dark color of the bath itself. In such cases it is well to have two flasks at hand, both containing the measured portions of bath and starch solution. Then by running iodine solution into one of the flasks and constantly comparing the color with the color of the liquid in the other flask, the point at which the change occurs may be more easily distinguished. Since the color is not at all permanent in the case of old and dirty baths, and since slight changes of tint are impossible to distinguish in such baths, it is good practice to add the iodine solution in quantities of 0.5 c. c. at a time when it is suspected that the end point is close at hand, then to mix thoroughly and immediately observe the color. This quantity of iodine solution is usually sufficient to produce a very pronounced change of tint if the end point of the titration really has been reached. The final reading should then be corrected by subtracting 0.25 or 0.50 c. c., whichever is judged nearest correct. The number of cubic centimeters of iodine solution needed to produce the blue color, multiplied by the strength of each cubic centimeter in terms of arsenic, and this again by 4, will give the grams of arsenic per 100 c. c. of bath—that is, the percentage. For instance, suppose that each cubic centimeter of iodine solution was found to be equivalent to 0.00239 gram arsenious oxid, and that 18.3 c. c. of iodine solution were employed in the titration of 25 c. c. of a bath under examination. Then the bath contains $0.00239 \times 18.3 \times 4 = 0.175$ per cent of actual arsenious oxid.

Theoretically, method "A" can not be applied with perfect accuracy to dipping baths, on account of the possibility that substances other than arsenious oxid—such as tar and organic matter derived from the cattle—may absorb some iodine and thus lead to false results. Practically, however, this method has been shown by many tests to give useful results on dipping baths of all ages prepared after the "standard formula" recommended by the Bureau of Animal Industry. (See p. 1.) That is, the various ingredients of the tar and the organic matter derived from cattle actually do not interfere fatally, but absorb iodine so slowly that the end point with starch is obtainable without difficulty, although it usually fades out in a brief time. Therefore, method "A" is suggested for use in the practical testing for ordinary purposes of baths prepared after the "standard formula." It must not, however, be employed on baths prepared from any proprietary dip unless it is certainly known that the particular dip contains no substance which can interfere. Since it is the present policy of the bureau to permit for use in official dipping only such proprietary preparations as may be satisfactorily tested by means of the field outfit later to be described, and since the field test is practi-

cally identical with method "A," the latter method may be safely employed for the examination of samples known to be prepared from proprietary dips which have received such official recognition.

METHOD "B" FOR ACTUAL ARSENIOUS OXID.

Measure 25 c. c. of bath into a small beaker, add 5 c. c. of 10 per cent sulphuric acid and 0.25 gram of acid-washed blood-charcoal. Stir thoroughly and heat nearly to boiling—best on a steam bath—for five minutes. Then filter and wash with hot water until the filtrate amounts to a little over 100 c. c. If the bath appears to be very heavily loaded with dirt or tar, the addition of about a gram of acid-washed kieselguhr (infusorial, siliceous, or diatomaceous earth), followed by thorough stirring before filtration, will greatly hasten the passage of the liquid through the filter. When the filtrate has been thoroughly cooled to room temperature, sodium bicarbonate is added until 1 or 2 grams are present in excess after effervescence ceases. In case the bath was prepared from a proprietary product, dilute to about 200 c. c. before adding sodium bicarbonate, and lastly also add 2 grams potassium iodid.¹ Finally, the solution is titrated with standard iodine and the result calculated as under method "A." If the greatest possible accuracy is desired a correction must be made for loss of arsenic through the use of blood-charcoal. This substance notably adsorbs arsenious oxid, and even after thorough washing a slight amount remains unaccounted for, which presumably still is retained by the charcoal. The amount of arsenic so lost appears—at least within practical limits—to be independent of the concentration of the bath, but is naturally dependent upon the amount of charcoal employed. Hence the charcoal must be rather carefully weighed or measured, and the amount of the correction for each lot of charcoal must be established by running comparative titrations on two portions of a solution of pure arsenious oxid, one direct, the other after the treatment with charcoal, filtration, and washing, which has been described.² The power of the charcoal to produce a water-white filtrate in which the blue end point is sharp and permanent far outweighs its disadvantages if accurate results are desired.

Method "B," like method "A," should not be applied to proprietary dips unless they are permitted for use in official dipping or are otherwise known to be free from interfering substances.

¹ Dilution and the addition of potassium iodid aids in nullifying the interfering effect of cresylic acid and other substances capable of absorbing iodine which may be present in proprietary dips. Phenols rapidly absorb iodine from a solution containing sodium bicarbonate. The presence of free carbonic acid, which of course saturates the liquid during titration, greatly reduces the rate of absorption. Finally, if the solution contains a certain concentration of potassium iodid, and not above a certain concentration of the phenols, the end point comes out perfectly sharp, of good color and permanency, following a titration figure which appears wholly unaffected by the presence of phenols.

² The sample of blood-charcoal at present in use in this laboratory demands a correction of 0.2 c. c. of twentieth-normal iodine for 0.25 gram charcoal.

METHOD FOR "TOTAL ARSENIC."

Strictly speaking the oxidized form of arsenic no longer contains arsenious oxid as such (As_2O_3) but only arsenic oxid (As_2O_5). Nevertheless, for the purpose of making simple and convenient comparisons, it is necessary to refer all quantitative statements regarding arsenic compounds to the common basis of their equivalent in arsenious oxid. Therefore, the term "total arsenic" is employed to signify all arsenic present in any form of combination or degree of oxidation, expressed in terms of arsenious oxid.

The method to be described is a standard method based on the well-known fact that the reaction $\text{As}_2\text{O}_3 + 4\text{I} + 2\text{H}_2\text{O} \rightleftharpoons \text{As}_2\text{O}_5 + 4\text{HI}$ is reversible, going from left to right in neutral or alkaline solutions, and from right to left in solutions which are freely acidified with a strong mineral acid. The reaction from left to right is the basis for the previously described methods for the determination of actual arsenious oxid. To determine total arsenic it is only necessary to allow the reaction to progress to completion from right to left, then to determine the resulting arsenious oxid in a manner similar to that already described.

The solutions and reagents necessary, in addition to the same standard iodine solution, starch solution, dilute sulphuric acid, and solid sodium bicarbonate, are anhydrous powdered sodium carbonate, solid potassium iodide, a one-tenth per cent solution of methyl orange, possibly concentrated sulphuric acid, and lastly a solution of sodium thiosulphate containing about 25 grams per liter.

The first step is to clarify and decolorize the solution. Hence proceed exactly as in method "B" for actual arsenious oxid (p. 8) until the filtered solution has been obtained. When both actual and total arsenious oxid are to be determined it is most convenient to double the quantities of both acid and charcoal, and to filter into a 200 c. c. volumetric flask. After thorough washing and cooling, the contents of the flask are made to the mark, mixed, and divided into two equal portions, one for actual arsenious oxid, the other for total arsenic. In either case transfer the solution containing the equivalent of 25 c. c. of the original bath to a 200 c. c. beaker, add 4 c. c. of concentrated sulphuric acid and about 2 grams of potassium iodide, boil gently until the volume of liquid is reduced to 50 c. c., then cool to room temperature. The next step is to remove free iodine from the solution. This may be done while the solution is still in the beaker, by adding the solution of sodium thiosulphate drop by drop from a burette until the yellow color of free iodine just disappears. Any excess of thiosulphate must be carefully avoided. A safer procedure for one not experienced with the method is to wash the contents of the beaker into a flask of 600 to 800 c. c. capacity, dilute

to about 200 c. c., nearly discharge the color of iodine by sodium thiosulphate, add a little starch solution, and continue the cautious addition of thiosulphate solution until the blue color disappears. Then add standard iodine solution from a burette until the faintest possible persistent blue remains. Whichever method is used, the solution at this stage should be in a capacious flask, and should be diluted to about 300 c. c. Add a few drops of methyl orange, then render alkaline by the cautious addition with a spatula of anhydrous sodium carbonate. When the solution is clearly alkaline wash down any solid adhering to the neck or sides of the flask and add dilute sulphuric acid until the reaction is clearly acid, taking care that no particles of sodium carbonate remain undissolved. Then add a liberal excess of sodium bicarbonate, 10 c. c. more starch solution, and titrate with standard iodine in the usual manner. The final titration should of course be corrected for the adsorption of arsenious oxide by blood-charcoal. No additional correction for adsorption of arsenic oxide appears necessary. No extra addition of potassium iodide appears to be necessary in case cresylic acid, etc., is present.

The above-described methods for actual arsenious oxide and for total arsenic have proved reliable for the examination of all products thus far permitted for use in official dipping, and it is probable that they will be found applicable to any proprietary products which may receive such official recognition in the future, though obviously a positive statement on this point can not be made. The experienced chemist will naturally think of other methods which might be applied. For example, the acidified and filtered bath may be treated in a separating funnel with ether or some other appropriate organic solvent to extract cresylic acid, fatty acids, etc.; total arsenic may be determined after the destruction of organic matter by appropriate digestion or incineration, or it may be separated by distillation; while it is known that some chemists prefer to determine directly arsenic existing as arsenic acid by titration with uranium acetate.

FIELD METHODS OF ASSAY.

A field method of assay is generally based upon a laboratory method; apparatus, reagents, etc., being simplified to the extreme in the interests of durability and portability, and the operations being reduced to the fewest and simplest, that they may be successfully executed by persons wholly unacquainted with chemistry as a science. But a skilled chemist in the laboratory to supervise the field tests is even more necessary than if all the work were actually performed in the laboratory itself, for upon his experience and care reliance must be placed to standardize the methods in such a way that useful data may actually result from the manipulation of inadequate apparatus by unskilled hands. Of course, it is only excep-

tionally that a laboratory method can be modified so that it is of any practical use whatever in the field, and in any event it is almost certain to lose something in accuracy. One thing is absolutely essential, that the field operator shall follow the instructions given him to the minutest detail, no matter how irrelevant or unimportant they may appear to him.

FIELD METHOD FOR ACTUAL ARSENIOS OXID.

The field method at present employed by the bureau for actual arsenious oxid is simply an adaptation of laboratory method "A" for the same substance. The outfit is pictured in figure 1, and each part composing it will be described in detail.

(1) *The case*.—The carrying case for the outfit is a rectangular box with a hinged cover, made of five-sixteenths-inch oak, of inside dimensions $7\frac{1}{2}$ by $5\frac{1}{8}$ by $1\frac{7}{8}$ inches. The interior partitions, of thinner and softer wood, are sufficiently indicated in the diagram. The case must be strongly mortised or nailed together, not simply glued, and should be varnished inside and out.

(2) *The utensils*.—Bottle A', fitting into compartment A of the case, is an ordinary 3-ounce wide-mouth bottle of clear glass.

Measuring cylinder C', fitting in compartment C, is of ordinary type, of 25 c. c. size, graduated to half cubic centimeters. Preferably the figures indicating the graduations read down only. C'' is a bristle swab for cleaning. It will be noted that the partitions of compartment C are cut away at the bottom to admit the foot of the cylinder. At the point *p* on the back wall of the case is fastened a quarter-inch pad of cork to protect the cylinder from breakage. The swab C'' is put into compartment C after the cylinder, thus protecting the latter from breakage on that side.

(3) *The reagents*.—The iodine solution, or, as it is termed for field use, the "test fluid," is contained in bottle D', a 4-ounce standard-shaped "sample oil" bottle, preferably of amber glass and provided with a "flat-hood" glass stopper. A half-inch ring of the $1\frac{3}{4}$ -inch (measured flat) thin rubber tubing, manufactured for use with Gooch crucibles, is drawn over the shoulder of the bottle, cemented in place, and coated with collodion. At the bottom of compartment D is fastened by a screw a conical spiral spring, the upper whorl of which is large enough to inclose the bottom of the bottle. In placing the latter in the case the bottom is inserted in the whorl of the spring and the bottle then pressed down until it slides into place. The partition between C and D is cut away in a semicircle at the point *q* to allow the fingers easy access to the bottle when it is to be removed.

The test fluid is of such strength that in the actual performance of the test each cubic centimeter of it employed represents exactly one

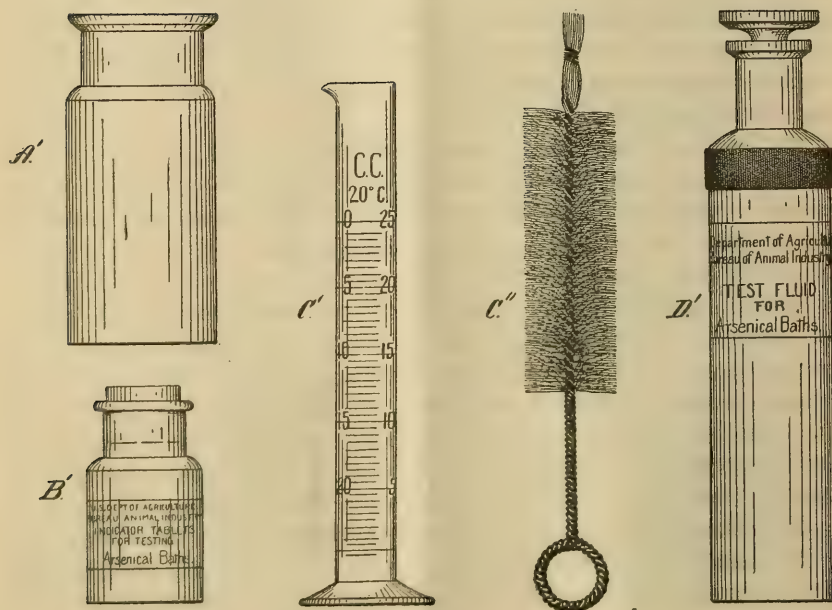
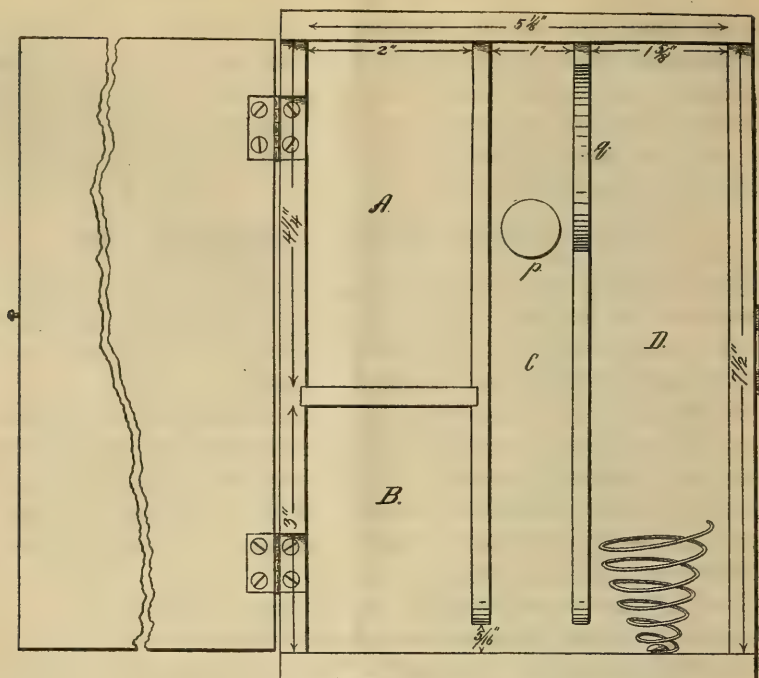


FIG. 1.—Test outfit for arsenic baths.

one-hundredth of 1 per cent of arsenious oxid in the bath under test. Therefore its strength should be originally fixed by standardizing it with the field apparatus against an average sample of used bath from the field in which the percentage (adjusted if necessary by the addition of a little concentrated solution of arsenious oxid in sodium carbonate) of actual arsenious oxid is close to 0.20 per cent and is accurately known through laboratory analysis. The true strength of this empirically standardized iodine solution should then be ascertained by titration against a strictly tenth-normal or twentieth-normal solution of arsenious oxid, and the result obtained may thereafter serve as the basis for the preparation of subsequent lots of test fluid. Obviously the true strength of the iodine solution will be influenced to some extent by the method of graduation of the cylinder, whether graduated "to contain" or "to deliver," and also by the depth of the meniscus, which in turn is influenced by the diameter of the cylinder. Hence, all field outfits under the supervision of a single laboratory should be fitted with cylinders of uniform model. Reserve supplies of test fluid should be kept in small, well-filled, tightly closed glass-stoppered bottles, and in a cool, dark place.

In addition to the test fluid, starch and sodium bicarbonate, or some equivalent substance, are of course necessary. In fact, the practical preparation of a satisfactory form of starch has been the greatest difficulty attached to the whole process, though at the same time the key to its success.

It has been known for many years that by the use of alcohol starch may be precipitated in water-soluble form, also that high-percentage, yet mobile, starch solutions may be obtained through proper treatment with hydrochloric acid, but the working out of a practical process for the preparation in quantity of a dry starch readily soluble in cold water and appropriate for use as an indicator appears not to be recorded.

Into a 5-liter round flask with a long neck is brought 400 grams potato starch, 2,300 c. c. distilled water, and, lastly, 80 c. c. of normal hydrochloric acid. The flask is well shaken to thoroughly wet and distribute the starch and is floated in a kettle of water previously brought to vigorous boiling. The neck of the flask conveniently rests on the side of the kettle at an angle of about 45° , and as soon as the flask is brought into the bath it is gently but continuously rotated about its longitudinal axis. As the flask becomes hot the starch forms an evenly distributed, uniform jelly, which in about 7 minutes from the time of starting begins to liquefy and to fall away from the wall of the flask. When this stage is reached the mouth of the flask is loosely closed with an inverted beaker and the flask left in the boiling bath with an occasional rotation until the liquid becomes mobile

and shows no lumps of gelatinized starch remaining, which should take a little over an hour. The flask is quickly cooled in running water until it can be comfortably handled, then a few drops of methyl orange are added, followed by concentrated ammonia to alkaline reaction. Next is added 800 c. c. of 95 per cent alcohol with thorough mixing, and after a few minutes standing to allow air bubbles to separate, the liquid is strained through moderately coarse muslin. The addition of this amount of alcohol is insufficient to permanently precipitate any starch, but notably thins out the original aqueous solution. Starch will separate some time after the solution has become cold, but with proper management ample time remains for the subsequent necessary operations. The solution, still at 40° to 45° C., is run through a number of fine jets into 4,000 c. c. of 95 per cent alcohol, under continuous stirring. The whole is left for at least 48 hours with an occasional thorough stirring, after which most of the supernatant alcohol is decanted, and the rest used to transfer the starch to a 2-quart narrow percolator provided with a filter plate which is covered with filter paper or cloth. Here it is percolated with 95 per cent alcohol, being stirred up with a stick at intervals to prevent the formation of clumps or fissures, until the alcohol comes through of a specific gravity indicating a strength of 90 per cent. The starch is then transferred to a Büchner funnel, well drained with suction, and then spread out to dry in a moderately warm place. The starch so prepared is a fine white powder, more or less compacted to friable lumps, which completely disintegrate under slight pressure. A little of it thrown into cold water in less than a minute dissolves sufficiently to yield a good blue upon the addition of iodine and potassium iodide. Moistened with water or diluted alcohol it becomes gummy and dries out to a horny mass, difficultly soluble in cold water. The efficiency of the preparation therefore is dependent upon its fine state of subdivision, and care must be taken during the process not to expose it to air until after thorough digestion with alcohol of 90 per cent strength. It should be passed through a 60 or 80 mesh sieve and protected from moist air.

The soluble starch may be thoroughly mixed with 10 times its weight of powdered sodium bicarbonate and the mixture divided into powders of about 0.6 gram, which may be packed in a pasteboard box fitting into compartment B of the case. On the large scale, however, it is much better to make the mixture up into tablets,¹ after the following formula:

¹ It is something of an art to make good tablets. No one should attempt it until thoroughly conversant with the principles of the process, and then only on a small scale until experience is gained.

Milk sugar in fine powder.....	grams..	100
Sodium bicarbonate, in powder.....	do.....	1,000
Mix, moisten with dilute alcohol, granulate, dry thoroughly at only slightly elevated temperature, and grind granules to pass a 20-mesh sieve.		
Mix granules with—		
Soluble starch.....	grams..	100
Raw potato starch.....	do.....	75
Talcum, U. S. P.....	do.....	25
Compress into tablets of 0.65 gram.		

The practical tablet maker will be tempted to criticize this formula because it carries so much powder; but since the soluble starch is ruined by wetting it can not be incorporated into the granules, so that there appears to be no escape from this drawback, which at any rate has not prevented the practical preparation of the tablets on a large scale for the use of the bureau.

The tablets are put up in the 1-ounce wide-mouth bottle B', fitting into compartment B of the case.

On the inside of the cover of the case is glued a printed instruction sheet, which is protected by pyroxylin varnish. The instructions read as follows:

UNITED STATES DEPARTMENT OF AGRICULTURE,
BUREAU OF ANIMAL INDUSTRY.

TEST CASE FOR ARSENICAL BATHS.

Not to be used on baths prepared from proprietary preparations except on special instruction.

Keep test fluid in a cool dark place in glass-stoppered bottles only.

DIRECTIONS.

1. Fill clean graduate with bath, setting the *top* edge of the surface of the bath on the upper graduation (zero or 25 c. c.), pour (draining out drops) into clean wide-mouth bottle, add one white indicator tablet, and gently swirl or shake till tablet is nearly all dissolved.

2. Rinse graduate with clean water, shake out adhering drops (or rinse with a little test fluid), and fill to upper graduation (zero) with test fluid, setting the *bottom* of the curved surface on the mark.

3. While gently swirling bottle, slowly pour in test fluid from the graduate until the blue or violet color remains permanent for a half minute throughout the entire contents of the bottle after thorough mixing. Avoid excess of test fluid, adding only a few drops at a time toward the end.

The number of cubic centimeters (reading at the *bottom* of the curved surface) of test fluid added to just produce the color gives the number of hundredths of 1 per cent of arsenious oxid in the bath.

If the assay is not performed at the vat directly after taking the sample, the same precautions to prevent changes in degree of oxidation must be observed as described under "Laboratory Methods for Actual Arsenious Oxid" (p. 4). The scope of application of the method is of course subject to exactly the same limits as laboratory method "A" for actual arsenious oxid (p. 6).

FIELD METHOD FOR "TOTAL ARSENIC."

Since, pending further investigation, it is not possible to credit arsenic in the higher form of oxidation (arsenic acid or arsenates) with definite value as a tickicide, the efficiency of dipping baths must be judged for the present solely on the results afforded by the test for actual arsenious oxid. On the other hand, studies of changes in the composition of a number of dipping baths in actual service in the field, together with practical experience, have so far failed to show a clearly defined danger that the average bath, in which the strength of actual arsenious oxid is maintained, is likely to reach a degree of oxidation which may render it dangerous to cattle. Nevertheless, in view of obvious possibilities in these two directions, it is desirable to possess a field method for the estimation of total arsenic. The method to be described makes use of a chemical reaction recently discovered by the writer,¹ namely, the reduction of arsenic acid to arsenious acid by thiosulphuric acid. After reduction and removal of excess thiosulphuric acid by iodine in acid solution, sodium bicarbonate may be added and the arsenious oxid, now representing the total arsenic, may be titrated in the usual way. The method is necessarily more complicated, more tedious, and less accurate than the simple method for actual arsenious oxid. Nevertheless, rather comprehensive tests by representatives of the bureau in the field indicate that, if conditions demand such a test and no better can be discovered, the one at hand will afford useful results.

In addition to the outfit and supplies already described, the following supplies are necessary:

1. "Red tablets":

Talcum powder, U. S. P.....	grams..	10
Raw potato starch.....	do....	30

Mix, and stir in 0.1 gram Sudan Red III dissolved in sufficient ether to distribute the color, and evaporate off ether at a moderate temperature with frequent stirring.

Add:

Sodium bicarbonate in fine powder.....	grams..	3
Special soluble starch.....	do....	10
Mix, and add potassium pyrosulphate powdered to pass a 40-mesh sieve.....	do....	125

Mix well and compress into tablets of such size that 1 tablet will neutralize 9 to 10 c. c. of normal alkali. The mixture, not being granulated, can not be run through the hopper of a power tablet machine, but must be fed by hand into the die from the table of the machine.

2. "Blue tablets":

Ultramarine blue.....	grams..	1
Talcum powder, U. S. P.....	do....	5
Sodium thiosulphate, crystallized, ground to pass 20-mesh sieve, and air-dried.....	do....	100

Mix and compress into tablets of such size that 1 tablet will be equivalent to about 22 c. c. of twentieth-normal iodine.²

¹ Journal of Agricultural Research, 1914, vol. I, p. 515.

² It is probable that potassium iodid should also be added in making up these tablets in order to prevent some oxidation of arsenious oxid by iodine in acid solution in case "oxidized arsenic" is originally present in amount sufficient to nearly completely use up the thiosulphate.

The directions for executing the test read as follows:

1. Use regular outfit. Measure 25 c. c. of bath into wide-mouth bottle and add 1 blue tablet. When entirely dissolved, add 1 red tablet, and after this has entirely fallen to powder gently but continuously swirl the bottle for 3 minutes, then let it stand for 7 minutes more with an occasional mixing.

2. Next add test fluid from the graduate until the blue color just remains permanent for at least 10 seconds throughout the whole of the well-mixed liquid. Add but a few drops at a time toward the end and avoid excess, but pay no attention to the actual volume of test fluid added at this stage.

3. Now add *two* white indicator tablets and agitate till mostly dissolved. Fill the graduate to upper mark (zero) with test fluid, adding it just as in the estimation of "actual arsenious oxid" until the blue color just reappears permanently, avoiding excess.

The number of cubic centimeters of test fluid thus added to bring back the blue color represents hundredths of 1 per cent of "total arsenic" in the bath.

If "oxidized arsenic" is present in only very small amount the results are likely to be somewhat low, owing to some formation of arsenious sulphid, but in any event such small amounts of "oxidized arsenic" are without significance. Again it is obvious that the quantity of thiosulphate used will not show the presence of "oxidized arsenic" in amount much over 0.2 per cent of the bath, but this appears amply sufficient, for if so much is present, in addition to the actual arsenious oxid, which of course is determinable in practically any amount, the bath certainly should not be used for dipping.

THE INTERPRETATION OF RESULTS.

The "standard arsenical solution" is recommended by the bureau for use in two strengths—first, 10 pounds of white arsenic and 25 pounds of sal soda to each 500 gallons, and, second, 8 pounds of white arsenic and 24 pounds of sal soda to each 500 gallons of bath. The theoretical percentages of arsenious oxid will therefore be practically 24 hundredths of 1 per cent for the 10–25 formula, and 19 hundredths of 1 per cent for the 8–24 formula. Practical experience, however, has shown that the baths work with perfect satisfaction so long as the percentages of "actual arsenious oxid" do not drop below the following limits: For the 10–25 formula, 22 hundredths of 1 per cent; for the 8–24 formula, 175 thousandths of 1 per cent. These figures therefore represent minimum percentages below which the contents of the respective baths in "actual arsenious oxid" should not be allowed to fall. The maximum allowed percentages of "actual arsenious oxid" should be but little above the theoretical figures; say, 25 hundredths of 1 per cent for the 10–25 formula and 20 hundredths of 1 per cent for the 8–24 formula.

Respecting the maximum allowable percentages of "total arsenic," it is not yet possible to make any statements based upon positive experimental evidence. One might tentatively set the following limits which experience has indicated to be within the margin of safety: 30 hundredths of 1 per cent for the 10–25 formula; 25 hundredths of 1 per cent for the 8–24 formula.



BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE



No. 77

Contribution from the Forest Service, Henry S. Graves, Forester.
May 7, 1914.

(PROFESSIONAL PAPER.)

ROCKY MOUNTAIN MINE TIMBERS.¹

By NORMAN DE W. BETTS,
Engineer in Forest Products, Forest Products Laboratory.

STRENGTH.

OBJECT OF THE TESTS.

Approximately one-fourth of the timber cut in Colorado during 1911 was consumed by the mining industries of that State. A number of different species are used, and their relative strength is of considerable importance both to miners and producers of mine timbers. Native Douglas fir, the so-called "red spruce" of the Rocky Mountain region, has been the wood most suitable for use in mines, but it is no longer available for a very large part of the supply. The forests of lodgepole pine and Engelmann spruce, containing also several minor species, must furnish the bulk of the material. The Forest Service, in cooperation with the University of Colorado, has tested these different timbers to determine their relative strength.

Since the timbers are used both green and air-dried, the influence of moisture on their strength is of interest, and material was tested in order to bring out this relation.

The relative value of fire-killed timber and of timber cut from growing trees has been the subject of much discussion. Since considerable dead timber is used in the mines, and a large supply is available, tests on this kind of material were included, with the idea of determining its strength in the round form for comparison with material cut green.

MATERIAL.

The material tested² consisted of round beams and of props and caps representative of the market run of timber used in the coal mines. The props were from 5 to 6 inches in diameter and 6 feet long; the caps from 5 to 6 inches in diameter and 8 feet long; the beams nominally 8, 10, and 12 inches in diameter and 16 feet long. Table 1 gives a list of the material tested, and shows the form and number of

¹ This paper is of interest to miners and producers of mine timbers and will be suitable for distribution in Idaho, Montana, Wyoming, Colorado, Nevada, Arizona, and New Mexico.

² The material for the tests described in this report was in part donated by the Northern Coal & Coke Co. of Denver and in part obtained from several national forests located in Colorado. The tests were made at the timber-testing station of the Forest Service, which is conducted in cooperation with the University of Colorado, at Boulder.

the specimens, the kind of wood, the locality where secured, and the number of the table in which the individual tests are recorded.

TABLE 1.—*Material tested.*

Species and form of material.	Individual test records given in—		Number of pieces.	Source.
	Table No.	Reference Nos.		
Lodgepole pine (shipment A):				
Round props.....	{ 11 12	{ 1 to 10..... 1 to 5.....	15	{ Yards of Northern Coal & Coke Co., at Louisville, Colo. Probably cut on the west slope of the divide in Colorado.
Caps.....	{ 13 14	{ 1 to 10..... 1 to 5.....	15	Do.
Lodgepole pine (shipment B):				
Round props.....	{ 11 12	{ 11 to 20..... 6 to 10.....	15	{ Yards of Northern Coal & Coke Co. Probably cut on east slope of the divide in Boulder Co., Colo.
Caps.....	{ 13 14	{ 11 to 20..... 6 to 10.....	15	Do.
Lodgepole pine:				
Beams.....	{ 15 16	{ 1 to 30..... 1 to 15.....	45	{ Gunnison National Forest, Colo. (Cut from live timber.)
Lodgepole pine (fire killed):				
Beams.....	{ 15 16	{ 1 to 15..... 1 to 30.....	45	{ Gunnison National Forest, Colo. (Cut from timber standing dead for 30 years.)
Alpine fir:				
Round props.....	{ 11 12	{ 1 to 9..... 1 to 3.....	12	{ Partly from yards of Northern Coal & Coke Co., partly from Arapahoe National Forest, Colo.
Caps.....	{ 13 14	{ 1 to 9..... 1 to 5.....	14	Do.
Engelmann spruce:				
Round props.....	{ 11 12	{ 1 to 11..... 1 to 7.....	18	{ Partly from yards of Northern Coal & Coke Co., partly from Pike National Forest, Colo.
Caps.....	{ 13 14	{ 1 to 11..... 1 to 5.....	16	Do.
Douglas fir:				
Round props.....	{ 11 12	{ 1 to 10..... 1 to 5.....	15	{ Partly from yards of Northern Coal & Coke Co., partly from Gunnison National Forest.
Caps.....	{ 13 14	{ 1 to 10..... 1 to 5.....	15	Do.
Bristle-cone pine:				
Round props.....	{ 11 12	{ 1 to 10..... 1 to 5.....	15	Pike National Forest, Colo.
Caps.....	{ 13 14	{ 1 to 10..... 1 to 5.....	15	Do.
Western yellow pine (shipment A):				
Round props.....	{ 11 12	{ 1 to 10..... 1 to 5.....	15	{ Pike National Forest, Colo. (Shipped as "Black Jack.")
Caps.....	{ 13 14	{ 1 to 10..... 1 to 5.....	15	Do.
Western yellow pine (shipment B):				
Round props.....	{ 11 12	{ 11 to 20..... 6 to 10.....	15	{ Partly from yards of Northern Coal & Coke Co., partly from Gunnison National Forest.
Caps.....	{ 13 14	{ 11 to 20..... 6 to 10.....	15	Do.

The material from the National Forests was received at the laboratory in a green condition. The timbers from the yards of the coal company were partially air-dried. Upon arrival at the testing station all green material was barked and some of the specimens were soaked in water, while others were piled to air-season. The object of the water-soaking was to keep the timber in a green condition until tested or, in the case of the dead beams, to increase the moisture content to a point which would enable them to be compared with green material. The material cut green and water-soaked is used as the basis for making the comparisons with air-dry material.

The water-soaked material was placed in a small pond during the summer months and the first tests were made after 60 days and the last after 125 days of soaking. No means were available to give complete submersion. The caps and props were tied in bundles of five and the beams were rafted, iron rails being used to help submerge a part of the material. At intervals of two or three days the bundles and the individual beams were turned to make the soaking as uniform as possible.

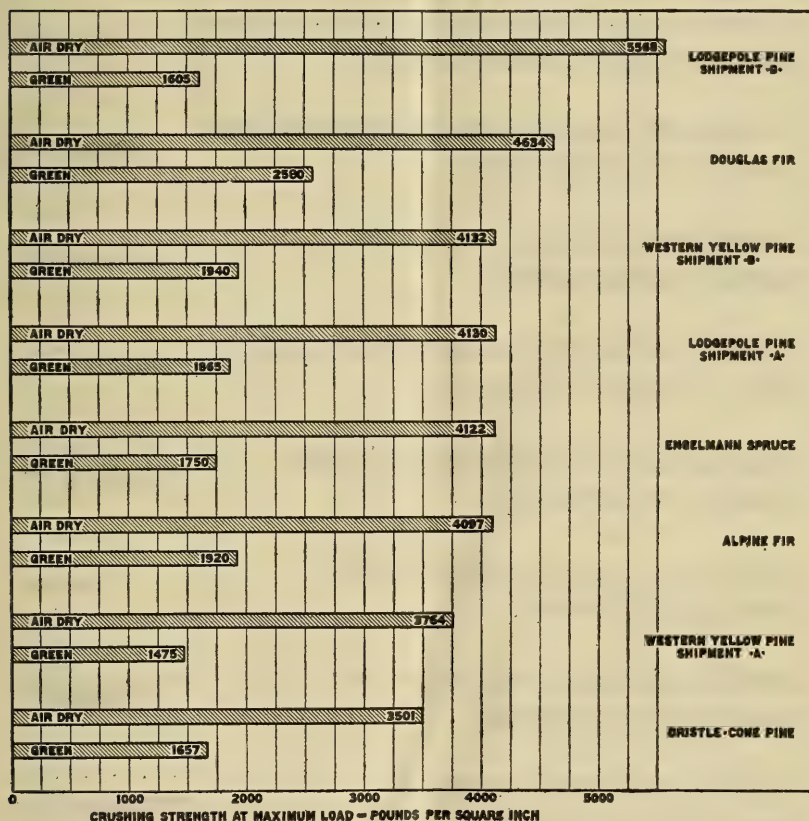


FIG. 1.—Comparison of different species; 6-inch round mine props—air-dried and green.

RESULTS OF TESTS.

Summaries of the results of the tests showing the average, maximum, and minimum of each group are presented in Tables 2 (props), 3 (caps), and 4 (beams). Results of the individual tests on the green props are recorded in Table 11, on the air-seasoned props in Table 12, on the caps in Tables 13 and 14, and on the beams in Tables 15 and 16.

PROPS AND CAPS.

The relative strength of air-seasoned and green material for each species and the relative strength of the different species are shown

graphically in figures 1 and 2. The increase in strength of the props due to seasoning is very evident in each species, and the average strength of the seasoned props of all species is 2.3 times that of the green ones at both maximum load and elastic limit. In the case of the caps the average strength of the dry timbers at the maximum load is 1.6 and at elastic limit 2.2 times the strength of the green timbers. While at the elastic limit the influence of the moisture

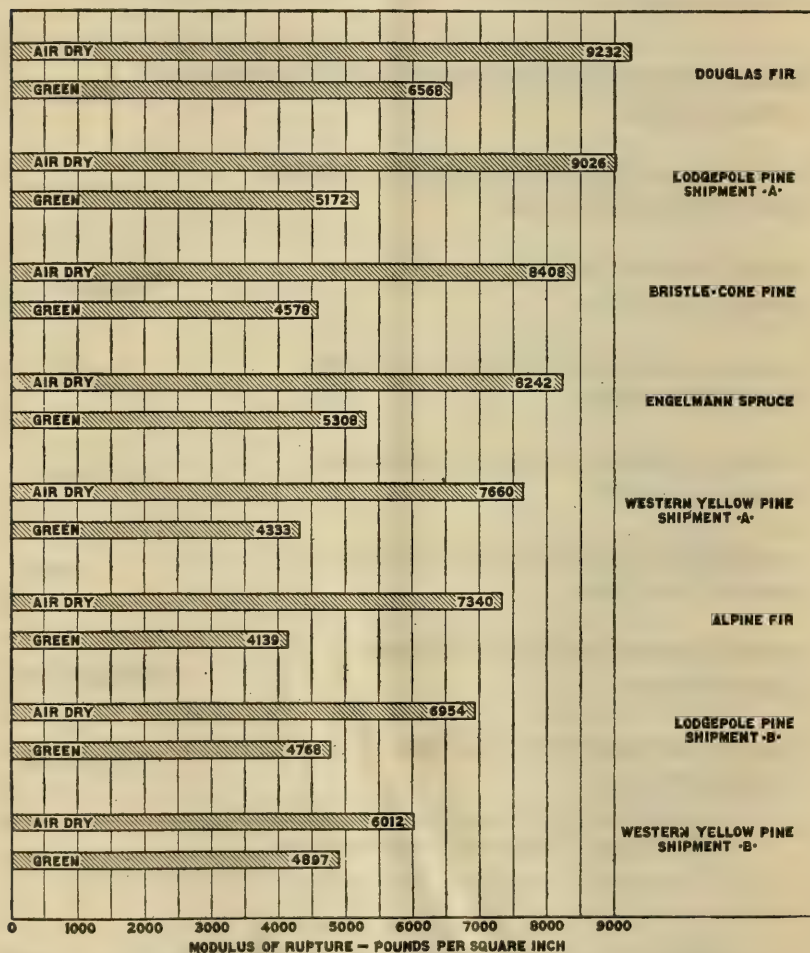


FIG. 2.—Comparison of different species; 6-inch round mine caps—air-dried and green.

was practically the same for both the crushing and bending tests, at the maximum load it is much more pronounced in the crushing tests. Stiffness in bending was increased by seasoning to 1.4 times the green value. There appears to be no marked variation in this strength ratio among the various species tested. It is slightly below the average in Douglas fir, due to the consistently high values for the green material in comparison with the other species,

TABLE 2.—Summary of crushing tests on round mine props (nominal size, 5-inch top by 6 feet long).

GREEN (WATER SOAKED).

Species, number of tests.	Moisture.	Rings per inch.	Diameter.		Crushing strength at maxi- mum load.	Crushing strength at elastic limit.	Modulus of elas- ticity.
			Top.	Butt.			
Lodgepole pine (shipment A); 10 tests:	<i>Per cent.</i>		<i>Inches.</i>	<i>Inches.</i>	<i>Lbs. per sq. in.</i>	<i>Lbs. per sq. in.</i>	<i>1,000 lbs. per sq. in.</i>
Average	75.7	40	5.73	6.18	1,865	1,495	599
Maximum	102.0	56	6.13	6.92	2,285	1,981	839
Minimum	48.3	28	4.93	5.33	1,440	1,049	343
Lodgepole pine (shipment B); 10 tests:							
Average	70.8	43	5.90	6.58	1,605	1,240	496
Maximum	108.2	58	7.00	7.56	1,890	1,559	621
Minimum	57.5	31	4.85	6.05	1,169	866	387
Alpine fir; 9 tests:							
Average	91.0	26	4.90	5.65	1,920	1,490	541
Maximum	123.6	42	5.37	6.05	2,355	1,944	706
Minimum	58.6	13	4.62	5.38	1,573	1,268	401
Engelmann spruce; 11 tests:							
Average	62.3	32	4.95	5.80	1,750	1,347	529
Maximum	89.1	46	6.20	7.08	2,115	1,755	686
Minimum	38.1	19	4.14	5.09	1,511	1,062	353
Douglas fir; 10 tests:							
Average	50.5	39	5.48	6.05	2,580	2,130	758
Maximum	91.6	76	6.84	7.16	2,870	2,438	865
Minimum	30.0	17	4.93	5.41	2,200	1,885	596
Bristle-cone pine; 10 tests:							
Average	85.9	35	4.58	5.38	1,657	1,310	508
Maximum	109.0	43	5.33	6.40	2,026	1,590	638
Minimum	56.1	31	3.98	4.77	1,364	965	390
Western yellow pine (shipment A); 10 tests:							
Average	96.1	14	4.44	5.20	1,475	1,201	443
Maximum	116.1	16	4.78	5.60	1,681	1,412	516
Minimum	83.2	13	4.14	4.94	1,269	1,038	345
Western yellow pine (shipment B); 10 tests:							
Average	82.0	18	5.35	6.00	1,940	1,450	561
Maximum	113.2	32	5.65	6.17	2,410	1,883	762
Minimum	54.8	11	5.01	5.73	1,668	1,132	448

AIR SEASONED.

Lodgepole pine (shipment A); 5 tests:							
Average	11.5	46	4.93	5.43	4,130	3,513	993
Maximum	12.3	57	5.17	5.57	4,770	4,190	1,194
Minimum	11.0	34	4.77	5.17	3,340	2,750	875
Lodgepole pine (shipment B); 5 tests:							
Average	12.2	45	4.81	5.44	5,568	4,438	1,282
Maximum	15.9	50	5.25	5.73	6,340	4,980	1,452
Minimum	11.0	42	4.01	5.01	4,980	4,010	1,135
Alpine fir; 3 tests:							
Average	11.6	18	4.27	5.28	4,097	3,530	978
Maximum	12.4	23	4.46	5.41	4,260	3,875	1,043
Minimum	10.5	15	4.06	5.09	3,910	3,165	890
Engelmann spruce; 7 tests:							
Average	11.8	33	4.42	5.29	4,122	3,297	1,042
Maximum	13.7	50	5.09	5.97	5,560	4,290	1,321
Minimum	10.9	16	3.50	4.62	2,990	2,410	703
Douglas fir; 5 tests:							
Average	12.3	49	4.85	5.33	4,634	3,617	1,131
Maximum	13.7	76	5.33	6.05	5,720	4,450	1,324
Minimum	11.5	28	4.30	4.62	2,960	2,340	873
Bristle-cone pine; 5 tests:							
Average	12.4	38	3.68	4.44	3,501	2,823	826
Maximum	12.6	45	3.98	4.85	4,390	3,512	1,023
Minimum	12.2	30	3.18	4.22	2,340	2,013	628
Western yellow pine (shipment A); 5 tests:							
Average	11.7	14	3.93	4.78	3,764	3,401	887
Maximum	13.4	16	4.30	4.85	5,330	4,780	1,146
Minimum	10.5	11	3.50	4.62	3,050	2,470	628
Western yellow pine (shipment B); 5 tests:							
Average	11.7	18	4.82	5.44	4,132	3,266	956
Maximum	13.0	31	4.93	5.65	4,790	3,770	1,160
Minimum	10.9	12	4.62	5.25	3,120	2,270	628

TABLE 3.—Summary of bending tests on round mine caps (nominal size, 5-inch top by 8 feet long; span, 7 feet; third-point loading).

GREEN (WATER SOAKED).

Species, number of tests.	Moisture.	Rings per inch.	Diameter.		Modulus of rupture.	Fiber stress at elastic limit.	Stiffness factor ($\frac{P}{Id}$)
			Top.	Butt.			
Lodgepole pine (shipment A); 10 tests:	<i>Per cent.</i>		<i>Inches.</i>	<i>Inches.</i>	<i>Lbs. per sq. in.</i>	<i>Lbs. per sq. in.</i>	
Average.....	89.3	43	5.59	6.20	5,172	3,104	98.0
Maximum.....	133.3	61	5.90	6.68	6,460	3,830	119.7
Minimum.....	56.7	23	5.17	5.60	4,040	2,635	72.1
Lodgepole pine (shipment B); 10 tests:							
Average.....	60.6	43	5.78	6.45	4,768	2,762	86.0
Maximum.....	89.5	52	6.00	6.75	6,180	3,555	126.2
Minimum.....	40.1	31	5.25	6.00	3,585	2,090	55.3
Alpine fir; 9 tests:							
Average.....	99.5	21	4.65	5.72	4,139	2,450	79.3
Maximum.....	147.2	36	5.63	6.50	5,260	2,910	108.8
Minimum.....	57.6	8	4.13	5.38	1,945	1,782	57.6
Engelmann spruce; 11 tests:							
Average.....	54.3	30	5.16	6.40	5,308	2,709	95.0
Maximum.....	74.6	45	6.00	7.00	7,280	3,665	130.5
Minimum.....	36.3	17	4.44	5.88	3,500	1,991	68.2
Douglas fir; 10 tests:							
Average.....	69.4	27	4.78	5.66	6,568	3,455	85.2
Maximum.....	119.1	38	6.25	7.00	7,310	4,675	107.9
Minimum.....	32.6	16	4.00	5.00	4,840	2,505	55.0
Bristle-cone pine; 10 tests:							
Average.....	74.3	37	4.63	5.62	4,578	2,459	66.6
Maximum.....	96.1	62	5.63	7.00	5,480	3,960	85.7
Minimum.....	66.2	25	3.98	4.00	3,500	1,666	48.3
Western yellow pine (shipment A); 10 tests:							
Average.....	88.5	13	4.39	5.60	4,333	2,170	74.5
Maximum.....	106.3	15	4.80	6.25	4,960	2,775	86.9
Minimum.....	71.1	12	3.75	4.75	3,860	1,553	59.1
Western yellow pine (shipment B); 10 tests:							
Average.....	147.1	26	4.42	5.45	4,897	2,890	72.6
Maximum.....	198.4	42	5.00	6.12	6,190	3,540	89.8
Minimum.....	86.5	15	3.62	5.00	3,320	2,148	35.9

AIR SEASONED.

Lodgepole pine (shipment A); 5 tests:							
Average.....	11.4	54	4.76	5.21	9,026	6,600	133.1
Maximum.....	11.9	72	5.09	5.49	11,630	8,640	152.2
Minimum.....	10.6	33	4.54	5.09	7,180	4,790	119.5
Lodgepole pine (shipment B); 5 tests:							
Average.....	11.1	44	4.84	5.49	6,954	5,962	114.5
Maximum.....	11.7	47	5.41	5.73	9,620	7,290	148.2
Minimum.....	10.6	42	4.54	5.33	4,490	4,230	84.1
Alpine fir; 5 tests:							
Average.....	11.4	26	4.22	5.28	7,340	5,460	108.5
Maximum.....	12.1	37	4.62	5.57	9,350	6,600	125.2
Minimum.....	10.4	20	3.66	5.09	5,270	4,320	85.2
Engelmann spruce; 5 tests:							
Average.....	10.9	37	4.41	5.35	8,242	6,618	118.5
Maximum.....	11.8	45	5.33	6.05	9,900	7,340	151.2
Minimum.....	8.8	27	3.50	4.62	6,260	5,190	72.0
Douglas fir; 5 tests:							
Average.....	11.8	23	4.30	5.20	9,232	6,842	126.3
Maximum.....	12.3	29	4.77	5.57	10,960	7,660	145.1
Minimum.....	11.4	15	3.82	4.77	5,790	5,100	92.8
Bristle-cone pine; 5 tests:							
Average.....	11.5	37	3.82	4.98	8,408	5,684	97.7
Maximum.....	12.5	52	4.22	5.25	9,550	6,700	116.1
Minimum.....	10.7	27	3.50	4.54	7,000	4,120	89.3
Western yellow pine (shipment A); 5 tests:							
Average.....	10.3	14	3.58	4.85	7,660	5,770	103.8
Maximum.....	10.6	15	3.66	5.09	9,770	7,730	118.2
Minimum.....	9.4	13	3.50	4.62	5,660	3,870	87.5
Western yellow pine (shipment B); 5 tests:							
Average.....	10.7	21	3.90	5.12	6,012	4,938	80.0
Maximum.....	11.4	26	4.22	5.41	7,360	5,830	112.6
Minimum.....	10.3	17	3.58	4.62	4,210	4,220	62.2

TABLE 4.—Summary of bending tests on round beams, 16 feet long (span, 15 feet; third-point loading).

GREEN (WATER SOAKED).

Species, size, number of tests.	Moisture.	Rings per inch.	Diameter.		Modulus of rupture.	Fiber stress at elastic limit.	Stiffness factor $\left(\frac{P}{ld}\right)$	Work to maximum load.
			Top.	Butt.				
Lodgepole pine, cut from live timber:								
8-inch butt, 10 tests—	<i>Per cent.</i>		<i>Inches.</i>	<i>Inches.</i>	<i>Lbs. per sq. in.</i>	<i>Lbs. per sq. in.</i>		<i>Inch lbs. per cu. in.</i>
Average.....	77.3	32	6.77	8.20	5,348	3,120	10.99	4.7
Maximum.....	99.4	37	7.32	8.75	6,210	4,200	13.42	6.6
Minimum.....	62.1	28	6.29	7.76	4,860	2,425	9.26	2.6
10-inch butt, 10 tests—								
Average.....	90.2	27	8.26	9.97	5,233	3,008	10.32	5.5
Maximum.....	118.2	32	9.23	10.74	6,230	3,905	11.73	7.8
Minimum.....	73.4	21	7.24	9.39	4,510	2,038	7.48	3.2
12-inch butt, 10 tests—								
Average.....	91.8	23	9.82	11.62	5,095	2,987	10.23	5.2
Maximum.....	99.6	24	10.82	12.41	6,270	3,780	13.70	7.0
Minimum.....	78.3	18	9.23	10.98	4,230	2,298	8.16	2.0
Lodgepole pine, cut from timber after standing dead for 30 years:								
8-inch butt, 5 tests—								
Average.....	38.1	44	7.00	8.50	5,448	2,905	10.38	5.3
Maximum.....	45.2	52	7.08	9.06	6,580	3,690	13.25	7.6
Minimum.....	35.0	34	6.92	7.80	3,570	2,210	8.00	2.3
10-inch butt, 5 tests—								
Average.....	40.1	40	8.21	10.24	4,940	2,950	8.84	3.4
Maximum.....	47.7	48	9.23	11.14	6,500	4,180	10.97	5.4
Minimum.....	29.8	35	7.56	9.71	3,870	1,592	7.09	1.6
12-inch butt, 5 tests—								
Average.....	37.2	28	10.00	12.47	4,430	2,320	7.71	4.3
Maximum.....	41.7	34	10.98	12.97	5,680	2,960	9.71	8.2
Minimum.....	27.8	24	9.31	11.77	3,820	1,828	5.18	2.0

AIR SEASONED.

Lodgepole pine, cut from live timber:								
8-inch butt, 5 tests—								
Average.....	16.8	32	6.99	8.04	7,748	5,018	14.05	3.8
Maximum.....	19.9	34	7.64	8.36	9,310	5,290	16.80	4.9
Minimum.....	15.2	29	6.37	7.64	7,160	4,640	12.43	2.7
10-inch butt, 5 tests—								
Average.....	17.1	25	8.09	9.77	6,948	4,816	13.33	3.1
Maximum.....	18.3	27	8.59	10.03	9,060	5,940	18.75	4.0
Minimum.....	14.6	23	7.08	9.55	4,480	3,190	10.31	1.5
12-inch butt, 5 tests—								
Average.....	19.3	22	9.73	11.51	5,409	3,741	9.57	2.3
Maximum.....	21.8	23	9.95	11.81	6,350	4,340	11.62	3.0
Minimum.....	17.7	21	9.55	11.14	3,745	2,875	6.85	1.2
Lodgepole pine, cut from timber after standing dead for 30 years:								
8-inch butt, 9 tests—								
Average.....	13.7	40	6.98	8.39	5,625	4,649	10.92	2.1
Maximum.....	14.6	51	7.64	8.91	7,780	6,720	12.51	5.6
Minimum.....	11.5	34	6.45	7.48	3,843	3,195	9.58	.8
10-inch butt, 10 tests—								
Average.....	12.9	34	8.27	10.11	5,166	4,489	10.54	2.3
Maximum.....	14.4	42	8.91	10.66	8,970	6,400	13.53	4.2
Minimum.....	12.1	24	7.64	9.31	2,690	2,585	8.06	.5
12-inch butt, 11 tests—								
Average.....	13.8	31	9.16	12.15	4,720	3,925	9.84	1.7
Maximum.....	16.6	37	11.14	12.49	7,310	5,960	12.29	3.8
Minimum.....	12.0	24	9.07	11.46	2,060	1,343	8.12	.4

The average results do not show a consistent difference in the relative strength of the various species tested. Figures 1 and 2 show that, with the exception of the green props and caps of Douglas fir and the dry props of lodgepole pine (Shipment B), there is not a very large difference in the strength of the various shipments.

is apparent from the various positions occupied by the different shipments of lodgepole pine and western yellow pine that species is not in itself a reliable guide to strength in the selection of material of this form and size. With clear material, consistent differences would probably be found between some of the species, but in the props especially the degree of straightness of the piece and the presence of knots seem of greater effect than the species.

BEAMS.

The results of the tests on the three sizes of 16-foot round beams of lodgepole pine are shown graphically in figures 3 and 4. With the exception of the work to maximum load, all the strength functions decrease in value with increase in the diameter of the beam. The amount of this variation differs in the different kinds of material, being least in the green, greatest in the air-dried, and intermediate in the dead timber. The reason for the decrease in the unit strength of the larger beams is not apparent. It is not due to visible defects, such as cause a decrease in the unit stress in large stringers when compared with small clear pieces cut from them, since the defects in the 8 and 12 inch beams did not differ in kind or in appearance. The fact that stiffness decreases in the same manner as strength corroborates this statement, since such defects as knots and checks do not generally affect stiffness up to the elastic limit. The difference may, however, be due, at least in part, to rate of growth, which increases in all cases with increase in diameter. The smaller beams were apparently cut from the suppressed growth of a fairly even-aged stand. The unit weight of the beams does not vary consistently with the strength. The dry weight per cubic foot of the air-dried beams is lowest in the 12-inch size, but for the dead beams the weight is highest in this size.

The relative values of the dead, green, and air-dried timbers are also indicated in figures 3 and 4. In strength the dead material falls between that of the air-dried and green, being close to the air-dried at the elastic limit and close to the green at the maximum load. The air-dried material is the stiffest, the green and dead having practically equal values for this factor. The closeness of the values for green and dead water-soaked material and a comparison of their curves with those of the dry timbers show very clearly the effect of moisture in reducing the stiffness and strength at the elastic limit. In work to maximum load, which is an indication of toughness, the order of the curves is reversed, the green and water-soaked beams having values about twice as great as the dry material. The position of the dead water-soaked beams, especially, brings out the fact that the greater brittleness of the dead or air-dried material is due to dryness and not to a deterioration of the wood. Drying the beams

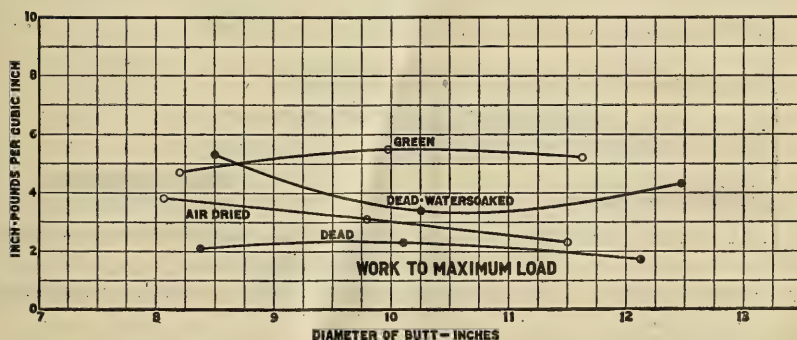
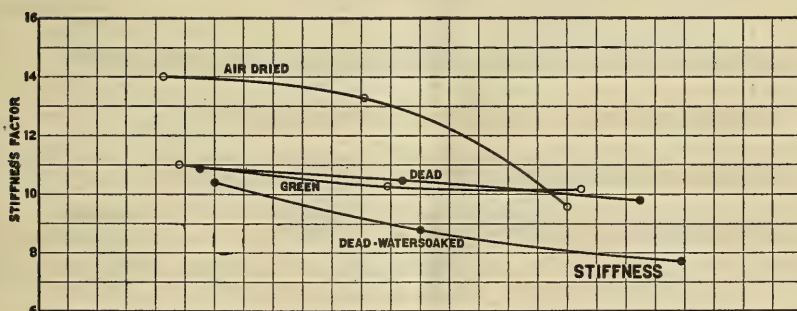
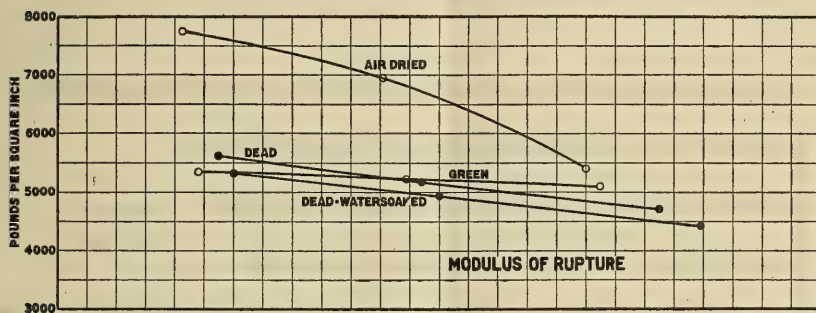
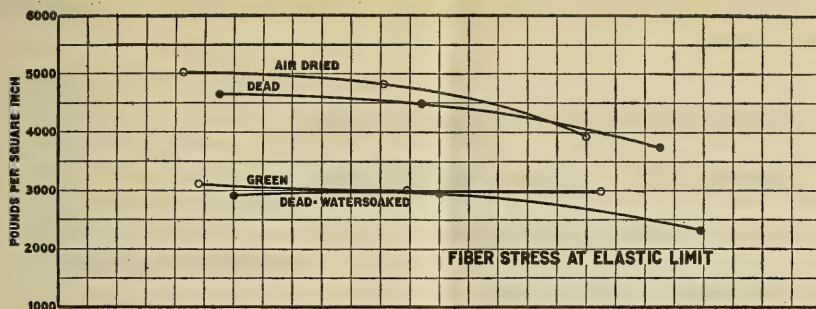


FIG. 3.—Relation of unit strength of 16-foot round beams to diameter and condition.

increased the strength and stiffness of the wood but decreased its toughness.

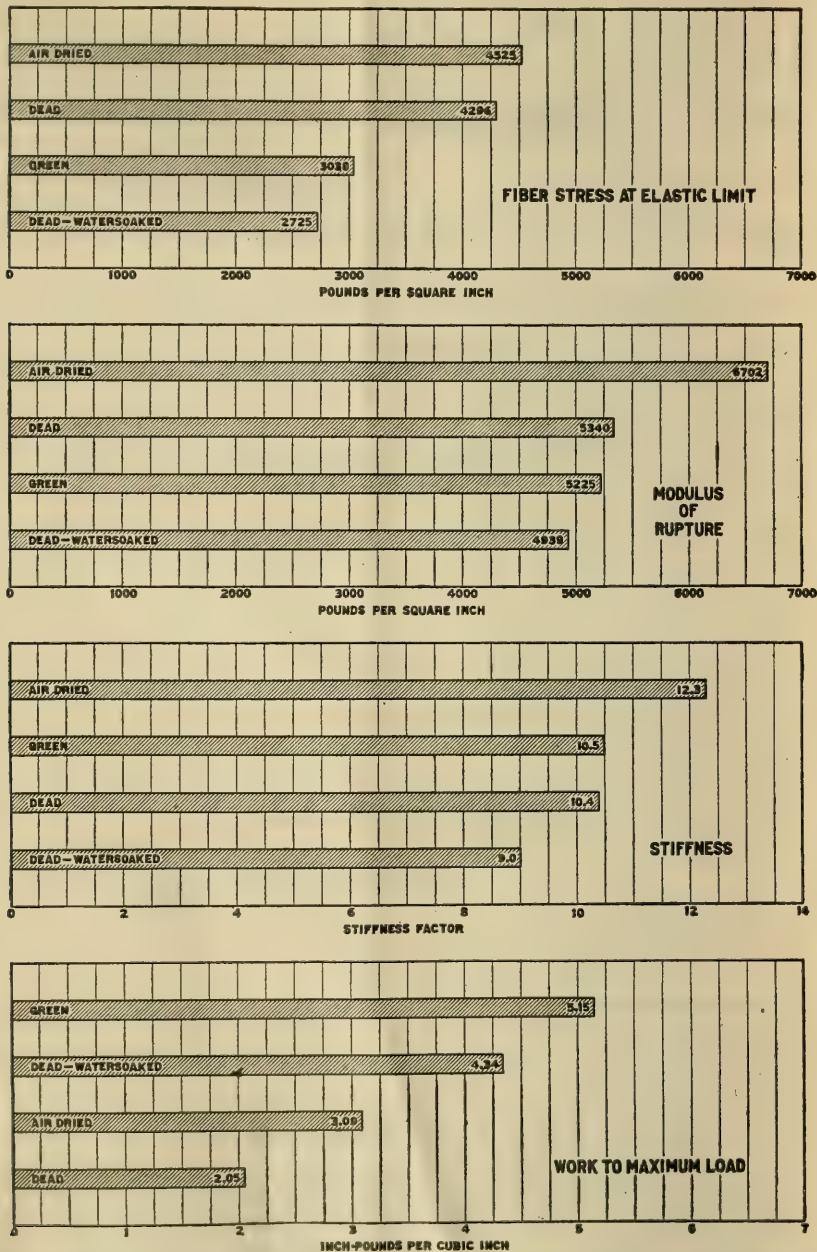


FIG. 4.—Relation of unit strength of 16-foot round beams to condition; based on average values of the three sizes tested.

In comparing fire-killed and green material, the grade of both, in regard to ordinary defects, should be taken into consideration. The

dead material tested was cut from an area supposedly burned over in 1880. In general, the surface was covered with a network of shallow worm marks (made when the bark was on and probably of no influence on the soundness). The beams, even the larger ones, were very rough and knotty, and were of poorer grade in respect to condition of knots than those cut green. The cross sections in general were sound, though here and there along the length were places beginning to form punky pockets at the surface. The fact that this material under test gave values up to the elastic limit nearly equal to those of the air-dried beams is of considerable interest, as it indicates that it is in excellent condition for the uses to which round material is ordinarily put.

CONCLUSIONS.

The tests indicate that:

1. An air-dried mine prop is superior to a green one as follows:
Strength at elastic limit 2.3 times as great.
Strength at maximum load 2.3 times as great.
Stiffness 1.9 times as great.
An air-dried mine cap is superior to a green one as follows:
Strength at elastic limit 2.2 times as great.
Strength at maximum load 1.6 times as great.
Stiffness 1.4 times as great.
2. With the exception of Douglas fir, there seems to be as much variation in the strength of one species procured in different places as among the different species themselves. This is probably the result of defects such as checks, knots, and bends, which, in this size of material (5 to 6 inch diameter round caps and props), apparently overbalance the differences in the actual strength of the clear wood.
3. The unit strength and stiffness of 16-foot round beams decrease with an increase in size. The smaller beams tested, however, represented a slower growth material and were probably suppressed trees.
4. Beams cut from timber standing dead for about 30 years showed a strength intermediate between green and air-dried material cut from live timber. The tests tend to corroborate the opinion that timber cut from dead trees can be graded on the same basis as other material; that is, the quality of the wood has not changed, from the fact that it has seasoned on the stump, and deterioration, if present, will be indicated by signs of decay. Checking in material to be used in the round form can hardly be considered as a defect, as it occurs in all air-dried round material.

CONSUMPTION AND DURABILITY.

CONSUMPTION OF MINE TIMBERS IN COLORADO.

The statistics here presented were collected to show the consumption of timber by the mining industry of Colorado¹ in 1911. They were obtained by sending a card to the mine operators of the State, requesting them to furnish the amounts, costs, and species of tim-

¹ Colorado was chosen partly because of its importance as a mining State; partly because for the year 1911 an estimate of the entire production of wood products, including lumber, poles, crossties, round mine timbers, and fuel was also available for direct comparison, and partly because the State is near the center of distribution of the species of mine timbers tested.

ber used in the mines, and information concerning the life of the timber and the extent to which methods to prevent decay had been employed. A small part of the material included may have been used in structures above ground.

Reports were requested from 823 operators, 110 of whom were coal-mine and 713 metal-mine operators. Out of 352 replies, 179 (15 coal-mine and 164 metal-mine operators) reported that no timber was used during 1911, while 173 operators reported the use of timber on which the following statistics are based.

In addition to the material reported by the tables, about 1,745 cords (or 872,500 b. m.) were used for fuel.

Nearly all the timber used came from within the State. About 800,000 board feet was reported as coming from outside, mostly Douglas fir from Oregon, with a small amount of pine from New Mexico.

The timbers for use in the coal mines ranged in size from about 5 to 7 inches in diameter and from 7 to 18 feet in length. In the metal mines 8 to 10 inch diameters were the principal sizes, though timbers varying from 6 to 20 inches were reported. Lagging was usually 3 to 4 inches at the small end, and mine ties were 4 by 4 or 4 by 5 inches in section and from 36 inches in length in the metal mines to 54 inches in the coal mines.

TABLE 5.—*Amounts and values of mine timbers used in Colorado in 1905, based on reports of mine operators.*

Mines reporting.	Number of mines.	Total amounts.		Total values.		Cost per M b. m.	
		Round, M b. m.	Sawed, M b. m.	Round.	Sawed.	Round.	Sawed.
Coal mines.....	69	7,893	457	\$153,152	\$15,428	\$19.40	\$33.76
Metal mines.....	418	18,152	13,061	284,861	251,798	15.69	19.28
Total (all mines).....	487	26,045	13,518	438,013	267,226	16.82	19.77
Aggregate.....		39,563 M b. m.		\$705,239			

TABLE 6.—*Amounts and values of mine timbers used in Colorado in 1911, based on reports of mine operators.*

Mines reporting.	Number of mines.	Total amounts.		Total values.		Cost per M b. m.	
		Round, M b. m.	Sawed, M b. m.	Round.	Sawed.	Round.	Sawed.
Coal mines.....	77	10,859	1,000	\$307,372	\$20,368	\$28.20	\$20.37
Metal mines.....	187	6,601	6,406	139,030	141,185	21.10	22.00
Total (all mines).....	264	17,460	7,406	446,402	161,553	25.50	21.80
Aggregate.....		24,866 M b. m.		\$607,955			

The amounts were reported in linear feet, in board feet (log scale), in cubic feet, and in cords. To reduce these various units to the

same basis 6 board feet were considered equivalent to 1 cubic foot of round timber and 500 board feet to a cord.

Table 5 is compiled from Forest Service Circular 49 for purposes of comparison. Table 6 gives similar data obtained for 1911. The two tables are not directly comparable, however, since the proportion of timber used by the mines reporting, to the whole consumption in the State, is not definitely known in either case.

PRODUCTION OF MINE TIMBERS IN COLORADO.

A study of timber products was made in Colorado for the year 1911, and this furnishes some basis for an estimate of the probable total consumption of timber by the mines, including both round and sawed forms. The total production, including lumber, crossties, mine timbers, poles, fuel, and farm timbers, on the basis of the reports of the national forest supervisors, for both Government and private lands, was 222,808,000 board feet. The total production of round mine timbers was 36,274,000 board feet. The consumption reported, as shown in Table 6, was 17,460,000 feet of round material and 7,406,000 feet of sawed lumber. If the figure for production may be assumed as approximately correct for the actual total consumption and the proportion between the amounts of sawed and round forms reported holds for the total consumption, the total sawed timber used in the mines would be 15,370,000 feet and the total timber, round and sawed, would be 51,644,000 feet. This represents close to \$1,250,000 in total value and 23 per cent of all the timber produced in the State.

PRODUCTION BY SPECIES.

The relative amounts of the different species used could not be obtained from the reports submitted by the mine operators. Based upon production, however, a close estimate is given in Table 7. The local names for certain species are different from those adopted by the Forest Service, and in order to make clear what woods are referred to, the scientific name, the common name used by the Forest Service, and the name used locally in Colorado are given below:

<i>Scientific name.</i>	<i>Common name used by Forest Service.</i>	<i>Common name used locally.</i>
<i>Pinus contorta.</i>	Lodgepole pine.	White pine.
<i>Pinus ponderosa</i>	Western yellow pine.	Black jack and yellow pine.
<i>Pinus flexilis.</i>	Limber pine.	
<i>Pinus aristata.</i>	Bristle-cone pine.	Fox-tail pine.
<i>Pseudotsuga taxifolia.</i>	Douglas fir.	Red spruce.
<i>Picea engelmanni.</i>	Engelmann spruce.	White spruce.
<i>Picea parryana.</i>	Blue spruce.	Water spruce.
<i>Abies lasiocarpa.</i>	Alpine fir.	Balsam.
<i>Abies concolor.</i>	White fir.	Black balsam.
<i>Populus tremuloides.</i>	Aspen.	Quaking-aspen.

TABLE 7.—Amounts by species of round mine timbers produced in Colorado in 1911.

Species.	Amount.	Percent- age of total.
	<i>Board feet.</i>	
Lodgepole pine.....	23,421,000	65.
Engelmann spruce.....	8,242,000	23
Douglas fir.....	2,244,000	6
Western yellow pine.....	1,354,000	4
Limber pine.....	431,000	1
Bristle-cone pine.....	183,000	
Aspen.....	149,000	
Alpine fir.....	109,000	
Blue spruce.....	75,000	1
White fir.....	65,000	
Oak.....	1,000	
Total.....	36,274,000	100

TABLE 8.—Unit costs for various diameters.

Diameter.	Cost per piece 16 feet long.	Cost per linear foot.	Cost per inch of diameter 16 feet long.
<i>Inches.</i>			
3	\$0.35	\$0.022	\$0.117
4	.40 to \$0.50	.025 to \$0.031	.100 to \$0.125
6	.45 to .65	.028 to .041	.075 to .108
8	.60 to 1.25	.038 to .078	.075 to .156
10	1.15 to 1.60	.072 to .100	.115 to .160
12	1.50 to 2.15	.094 to .135	.125 to .180
14	2.00 to 2.25	.125 to .141	.143 to .161
16	2.50	.156	.156

Table 7 shows that lodgepole pine is the main source of supply for round mine timbers, and, together with Engelmann spruce, makes up 88 per cent of all the props cut. Douglas fir, although a very desirable wood, formed only 6 per cent of the total.

COSTS FOR DIFFERENT SIZES.

Table 8, giving costs for props of various diameters, was compiled from such data submitted by the operators as were definite in regard to the size of the material. Several methods of purchasing round material were reported—cost per piece for a given length and diameter, cost per linear foot for a given diameter, and cost per inch of diameter at the small end for a given length. A large majority reported the cost per linear foot.

LIFE OF TIMBERS.

There was a large variation in the reported life of timbers in the different mines, especially in the metal mines. The timbers in the coal mines had an average life of only about one-half that found in the metal mines, but their size was also only about one-half as great. Tables 9 and 10 give the average values obtained from statements of the operators.

TABLE 9.—*Reported life of untreated round mine timbers in coal mines (mostly 5 to 7 inches diameter).*

Conditions in mine.	Douglas fir.	Pine. ¹	Engelmann spruce.	Alpine fir.	Piñon.
	Years.	Years.	Years.	Years.	Years.
Average.....	5	4	4	3	4
Poor ventilation.....	2	1	1	.....	1
Good ventilation.....	10	8	8	.....	6
Exceptional.....	25	15	.....	10	.....

¹ Includes lodgepole pine and western yellow pine.TABLE 10.—*Reported life of untreated round mine timbers in metal mines (mostly 8 to 10 inches diameter).*

Conditions in mine.	Douglas fir.	Western yellow pine.	Lodgepole pine.	Engelmann spruce.
	Years.	Years.	Years.	Years.
Average.....	9	9	7	8
Very poor ventilation.....	2 to 5	1 to 3	1 to 2	1 to 2
Constantly wet.....	20 to 40	15 to 25	.....	15 to 20

The conditions under which the estimates were made vary so much that the relative life of the different species is probably not reliable. For example, several operators reported that under the same conditions Douglas fir outlasts lodgepole pine or spruce two to three times; yet the average values show comparatively little variation among the species.

The factors that cause variation in the life of the timbers are principally ventilation, moisture, acid mine water, and the condition of the timbers when placed. The influence of fresh and comparatively dry air was clearly indicated in several mines which reported a life fully four times as long for the timbers in the intake shaft as for those in the return shaft (8 and 2 years, respectively). Several operators reported that they had increased the life of their timbers from two to three times by peeling and seasoning them before placement. Certain mines reported that their timbers were sound after standing from 25 to 35 years under conditions where they were nearly always wet, and in one or two cases the water was stated to contain "sulphuric acid" or "copper and arsenic," which probably acted as an antiseptic. Both constantly wet and constantly dry conditions appear, from the replies, to be favorable to a long life, while dampness, due to stagnant air, or alternating dryness and wetness, appears to furnish the best conditions for the growth of wood-destroying fungi.

PRESERVATIVE TREATMENT.

Preservative treatment to prevent decay was not regularly practiced at any of the mines reporting. Sixteen operators referred to some use of preservatives, though none had had a long enough experience to furnish data on the increased life from such treatment. The methods spoken of were dipping in creosote or crude oil, and brush

treatments with creosote, carbolineum, or crude oil. One operator referred to the disagreeable effect on the miners of the odor from the creosote in the mine.

There was great variation in the replies to the question regarding the proportion of timber used for replacements made necessary by decay. Replies from 30 coal mines averaged 11 per cent (14 reporting 0 per cent and none 100 per cent), and from 112 metal mines averaged 21 per cent (44 reporting 0 per cent and 11 reporting 100 per cent). It is apparent that the economy of preservative treatment is a local problem with each mine.

In order to decide whether it would be economical in any given case to apply treatment only a few factors concerning the present costs and life of the timbers are essential. The proper method¹ of treatment would depend upon species of wood, capacity of apparatus, and local conditions, but the preliminary steps could be taken on the basis of the following data:

1. The amount and cost of material that goes annually toward replacing decayed timbers.
2. The cost, in place, of the timbers used.
3. The average life of the timber.

The first of these factors will readily show whether the amount concerned is large enough to warrant further consideration of preservative treatment. In certain coal mines, where but few timbers are necessary in the permanent entries and where the majority of timbers are used in temporary positions, a brush treatment would probably be all that is warranted, unless impregnated material could be procured in the market. On the other hand, where a large amount of material is used to replace decayed timbers the installation of a small treating plant might be seriously considered.

From the cost in place and the average life of the timbers there can be calculated an annual charge, a measure of the relative economy, with which any other combination of cost and life (such as that resulting from a preservative treatment of the timber or perhaps from the use of some other kind of material) can be compared. In figure 5 is presented a series of curves, each for a definite initial cost of a timber or set of timbers, which show the relation between *length of life* and *annual charge* when compound interest on the investment is considered and maintenance is assumed for an indefinite time:²

¹ Forest Service Bulletin 107, The Preservation of Mine Timbers, by E. W. Peters, treats of various methods of preserving mine timbers from decay.

² The annual charges are figured on this basis so that a fair comparison can be made between different methods involving various combinations of costs and length of service. If a material were placed that would last forever its annual charge would be simply the interest on the cost in place. If the material must be replaced every so often, the annual charge represents the interest on a sum of money which, if placed at compound interest, would pay for the initial cost in place and all future replacements and would be itself used up at the end of the period of maintenance under consideration. If this period be of an indefinite length (forever), the annual charge is the interest on a sum of money sufficient to pay the present cost of installation and, by the accumulation of compound interest on the balance, take care of future replacements at the assumed intervals of time.

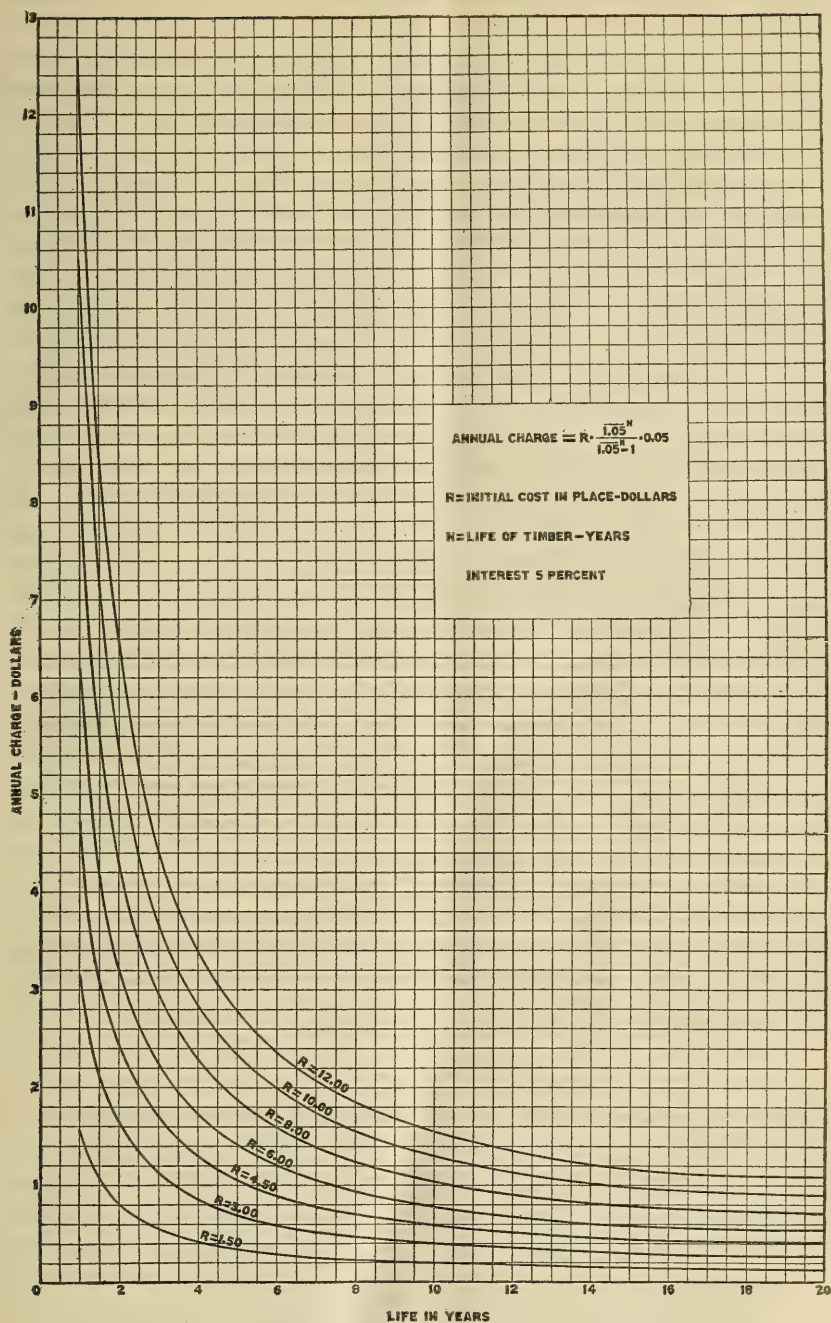


FIG. 5.—Relation between life of timbers and annual charge.

The curves will show how much additional initial cost is warranted when a given increase in life due to the treatment under consideration is assumed and the initial cost and life for the existing conditions are known. The diagram also illustrates graphically, by the steepness of the curves, the great economy in prolonging the life of timbers that ordinarily last but a few years.

To illustrate the use of the curves, assume that an operator wants to find out approximately what saving he would effect by carrying out some proposed scheme to lengthen the life of his timbers in certain permanent openings. Assume that each timber set costs \$6, including the expense of framing and setting. If its life is five years, its annual charge as shown by the curves is approximately \$1.40. Let us next assume that the proposed treatment will double the life; that is, give the timbers a service of 10 years. A further inspection of the curves at the line of 10 years' life shows that the same annual charge of \$1.40 results from an initial cost of \$10.50. In other words, the economy of a timber that costs \$6 in place and lasts five years is the same as one that costs \$10.50 and lasts 10 years; and, therefore, the proposed treatment would pay if the final cost of the treated timber was anything less than \$10.50. If we assume the cost of the treatment to be \$1.50 for each timber (making the total cost in place \$7.50) the annual charge would be about \$1. The cost of using treated timbers would increase the total cost of timbering each year until the period of the natural (untreated) life of the timbers (five years in this example) had been passed; after that time, however, there would be a period of very low total costs until it was necessary to replace the treated material. The economy shown in an annual charge of \$1 in comparison with \$1.40 represents the average conditions due to a continuous maintenance. It means, expressed in another way, that the investment required to maintain the untreated timber permanently would be \$28, and that the investment for the maintenance of the treated timber would be \$20, under the conditions given in this example.

APPENDIX.

METHODS.

TESTING.

The 6-foot props were tested in compression parallel to the grain at a speed of 0.119 inch per minute. A bearing block was used between the prop and the base of the machine. The compression of the prop, as indicated by the movement of the head of the testing machine, was read to thousandths of an inch by means of an Olsen deflectometer. Figure 6 shows a prop in the testing machine after failure.

The 8-foot caps were tested on a 7-foot span with third-point loading. The tests were made on a 200,000-pound Riehle testing machine at a speed of 0.231 inch per minute. The ends were supported by curved cast-iron bearing blocks and the load applied at two points (one-third the length of the span from either end) through curved wooden blocks. Deflections were read at the center of the beam to hundredths of an inch by observing on a taut string the movement of a polished metal scale attached to the timber. The method of loading is shown in figure 7, all parts of the testing machine being omitted except the weighing platform.

The 16-foot lodgepole pine beams were tested on a 15-foot span with third-point loading. The arrangement was similar to that used for the caps.

MOISTURE DETERMINATIONS.

A 1-inch section was cut from near the point of failure of each piece tested. This was immediately weighed and later dried to constant weight at the temperature of boiling water. The loss in weight divided by the dry weight, expressed in per cent, is the moisture content of the piece.

GENERAL OBSERVATIONS.

The length, weight, and diameters of the timbers were obtained just before testing. The rings per inch and the proportion of sapwood and of summerwood were obtained from a section cut near the point of failure. The values for the amount of summerwood are approximate, as the summerwood bands were not distinctly marked in many of the pieces.

COMPUTATIONS.

The load and deflection at the elastic limit were obtained from the load-deflection curve, and at maximum load by direct observation.

The fiber stress at the elastic limit and the modulus of rupture were computed for the diameter and moment of inertia obtaining under the smaller loading point, the section being regarded as a

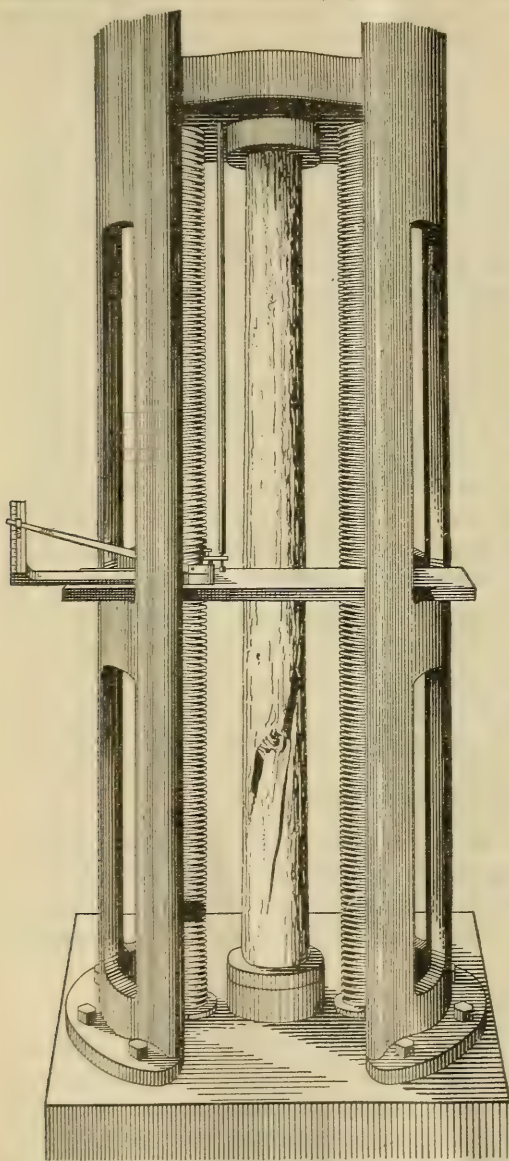


FIG. 6.—Method used in testing mine props in compression.

the butt, and the mean proportional between them, by the length. The weight per cubic foot was obtained from this estimated volume, and is therefore given as "approximate."

true circle. The stiffness factor $\frac{P}{Id}$ was obtained

from the moment of inertia (I) and the deflection (d) at the center of the beam. These values for stiffness are comparable for pieces of the same span only. The true modulus of elasticity, which is difficult to obtain accurately for a beam with a varying moment of inertia, depends upon the cube of the span. This relation is not considered in the "stiffness

factor" used, $\frac{P}{Id}$, and this

causes the values for the 7-foot span to be approximately ten times as large as for the 15-foot span. The work to maximum load was calculated from the area under the load-deflection curve, and is given in terms of unit volume. In the calculations involving the unit stresses of the props, the top area of the prop was used.

The volume of the test pieces was calculated by multiplying the average of the areas of the top,

TABLE 11.—Data on individual crushing tests of green round mine props (nominal size, 5-inch top by 6 feet long).

Species.	Reference No.	Moisture.	Approximate dry weight (volume as tested).	Rings per inch.	Summerwood.	Sapwood.	Diameter.		Crushing strength at maximum load.	Crushing strength at elastic limit.	Modulus of elasticity.	Remarks.
							Top.	Butt.				
Lodgepole pine (shipment A).	1	63.4	26.23	47	26	55	5.17	5.33	1,885	1,620	587	Grain slightly spiral. Slightly crooked.
	2	85.6	22.50	47	20	73	4.93	5.57	1,440	1,049	559	
	3	64.0	24.18	40	17	41	6.13	6.37	1,756	1,356	652	Grain slightly spiral.
	4	99.0	22.23	38	16	66	5.65	5.89	1,808	1,595	833	
	5	48.3	24.72	28	15	28	5.89	6.13	2,285	1,981	839	5 knots in failure plane. Unusually knotty. Grain spiral.
	6	65.3	22.79	43	16	50	6.13	6.92	1,835	1,356	582	
	7	102.0	21.48	56	20	54	5.57	6.13	1,820	1,396	546	Do. Do.
	8	83.7	23.46	32	13	62	5.81	6.45	1,745	1,509	560	
	9	67.4	24.22	32	14	65	5.99	6.53	1,800	1,420	602	
	10	78.4	25.70	36	18	46	6.05	6.45	2,281	1,670	719	
Av'ge.		75.7	23.75	40	18	54	5.73	6.18	1,865	1,495	599	
Lodgepole pine (shipment B).	11	61.8	24.57	41	18	50	5.81	6.13	1,712	1,130	539	Slightly crooked.
	12	63.3	23.08	46	22	55	6.05	6.84	1,490	1,250	387	
	13	58.7	26.40	45	20	25	6.13	6.53	1,890	1,559	442	Do.
	14	81.0	22.76	48	20	29	5.65	6.45	1,782	1,354	468	
	15	57.5	19.45	58	13	31	5.25	6.05	1,630	1,292	598	Grain spiral. Do.
	16	82.4	22.86	38	15	58	5.73	6.21	1,705	1,396	621	
	17	108.2	24.38	35	12	73	4.85	6.21	1,169	866	439	Slightly decayed. Grain spiral.
	18	61.8	22.21	44	16	53	5.73	6.37	1,655	1,318	481	
	19	69.6	20.56	31	12	50	6.76	7.42	1,438	891	526	
	20	63.7	22.39	48	14	55	7.00	7.56	1,590	1,351	463	
Av'ge.		70.8	22.86	43	16	48	5.90	6.58	1,605	1,240	496	
Alpine fir...	1	58.5	19.44	23	12		5.17	6.05	1,770	1,334	463	Grain slightly spiral. Do.
	2	38.6	24.07	42	15	.....	5.37	5.73	2,355	1,944	706	
	3	119.9	20.03	32	18	.....	4.70	5.38	1,712	1,441	502	
	4	115.3	.....	28	22	.....	4.90	5.58	1,573	1,378	401	
	5	86.3	22.41	25	20	.....	5.00	5.50	1,930	1,630	547	
	6	78.1	20.28	13	14	.....	4.77	5.65	1,870	1,568	519	
	7	123.6	21.58	23	16	.....	4.85	5.41	1,978	1,300	633	
	8	63.1	22.82	20	10	.....	4.70	5.65	2,007	1,268	486	
	9	135.7	20.22	29	9	.....	4.62	5.57	2,082	1,551	614	
Av'ge.	.....	91.0	21.36	26	15	.....	4.90	5.65	1,920	1,490	541	
Engelmann spruce.	1	52.4	23.32	32	13		5.65	7.08	2,040	1,755	642	Crooked. Grain spiral. Crooked.
	2	68.8	24.14	46	18	.....	6.20	7.00	2,000	1,459	686	
	3	53.1	24.08	38	14	.....	5.25	5.73	1,875	1,293	578	
	4	75.4	22.98	25	16	.....	4.38	5.41	1,511	1,062	358	
	5	89.1	22.82	25	20	.....	4.46	5.16	1,515	1,280	459	
	6	73.2	24.20	19	14	.....	4.14	5.09	1,590	1,340	592	
	7	72.2	22.96	26	15	.....	4.77	5.41	1,663	1,230	518	
	8	53.8	25.46	28	16		4.62	5.25	1,536	1,192	422	Grain slightly spiral. Crooked.
	9	55.8	23.79	42	14	.....	4.93	5.41	1,888	1,362	538	
	10	53.3	27.38	46	20	.....	4.38	5.49	2,115	1,725	608	
	11	38.1	23.66	24	14	.....	5.65	6.76	1,518	1,115	416	
Av'ge.		62.3	24.07	32	16		4.95	5.80	1,750	1,347	529	
Douglas fir..	1	89.1	27.34	20	26	68	4.95	5.45	2,622	2,180	799	Grain spiral. Do.
	2	34.9	25.22	40	24	14	5.33	5.81	2,870	2,242	596	
	3	91.6	24.29	23	22	52	5.41	6.05	2,715	2,438	765	
	4	66.9	25.33	38	14	42	5.60	6.30	2,200	1,946	718	
	5	37.8	28.57	61	24	19	4.93	5.73	2,358	1,885	676	Do.
	6	38.2	27.08	40	28	26	6.84	7.16	2,664	2,176	856	
	7	42.9	27.52	45	23	31	5.73	6.45	2,730	2,330	796	Do.
	8	34.8	31.84	26	17	38	5.01	5.57	2,560	2,030	718	
	9	30.0	30.10	76	25	12	5.89	6.61	2,545	1,908	789	Do. Do.
	10	38.5	27.77	17	28	70	5.09	5.41	2,560	2,160	865	
Av'ge.		50.5	27.50	39	23	37	5.48	6.05	2,580	2,130	758	

TABLE 11.—Data on individual crushing tests of green round mine props (nominal size, 5-inch top by 6 feet long)—Continued.

Species.	Reference No.	Moisture.	Approximate dry weight (volume as tested).	Rings per inch.	Summerwood.	Sapwood.	Diameter.		Crushing strength at maximum load.	Crushing strength at elastic limit.	Modulus of elasticity.	Remarks.
							Top.	Butt.				
Bristle-cone pine.	1	86.7	30.78	34	22	56	4.25	5.13	1,474	1,128	390	Crooked.
	2	109.0	26.83	32	19	56	4.65	5.50	2,026	1,590	638	
	3	74.9	30.86	33	18	39	4.80	5.50	1,364	1,050	453	
	4	106.1	26.17	41	21	36	5.33	6.40	1,690	1,435	505	Crooked and unusually knotty. Do. Grain slightly spiral.
	5	94.5	29.57	31	22	47	4.52	4.91	1,480	1,185	525	
	6	56.1	25.68	31	24	.....	3.98	4.77	1,400	965	446	
	7	60.3	28.95	38	16	51	4.46	5.17	1,760	1,408	574	
	8	85.1	25.83	43	23	46	5.17	6.05	1,828	1,430	464	
	9	101.0	25.72	32	16	43	4.38	5.16	1,941	1,528	571	
	10	85.5	26.39	39	16	38	4.30	5.17	1,610	1,378	516	
Av'ge.		85.9	27.68	35	20	46	4.58	5.38	1,657	1,310	508	
Western yellow pine (shipment A.)	1	91.8	22.67	14	14		4.25	5.25	1,355	1,128	428	Do.
	2	97.7	23.09	16	19	.....	4.25	5.00	1,630	1,410	516	
	3	88.9	22.52	13	14	.....	4.35	5.10	1,443	1,211	345	
	4	92.0	23.55	14	14		4.70	5.40	1,269	1,038	451	Crooked. Do. Do.
	5	83.2	22.48	13	15	.....	4.65	5.60	1,322	1,060	402	
	6	104.5	22.33	13	12	.....	4.30	5.13	1,481	1,172	475	
	7	101.2	22.71	14	16		4.78	5.16	1,518	1,119	438	Grain slightly spiral. Do.
	8	96.6	23.62	15	15	.....	4.38	5.41	1,522	1,262	448	
	9	89.3	25.70	15	13	.....	4.14	4.94	1,681	1,412	512	
	10	116.1	.....	13	15	.....	4.62	5.01	1,512	1,193	416	
Av'ge.		96.1	23.18	14	15		4.44	5.20	1,475	1,201	443	
Western yellow pine (shipment B.)	11	81.1	25.68	32	14		5.25	6.15	2,000	1,570	611	Unusually knotty. Grain slightly spiral. Do.
	12	90.5	23.22	11	14	.....	5.01	5.73	1,726	1,320	457	
	13	83.0	24.80	24	20	.....	5.65	6.13	1,668	1,275	448	
	14	113.2		19	23		5.33	6.17	2,055	1,435	491	Grainspiral, crooked.
	15	54.8	25.92	19	17	.....	5.49	6.05	1,682	1,352	478	
	16	63.5	21.58	16	13	.....	5.41	6.05	1,670	1,132	532	
	17	78.8	24.62	16	15	.....	5.33	5.97	2,410	1,883	702	
	18	105.5	24.78	16	12	.....	5.49	5.81	1,950	1,269	458	
	19	76.6	26.20	16	14	.....	5.41	6.05	2,005	1,392	569	
	20	72.8	26.28	14	13	.....	5.09	5.89	2,225	1,865	762	
Av'ge.		82.0	24.78	18	16		5.35	6.00	1,940	1,450	561	

TABLE 12.—Data on individual crushing tests of air-seasoned round mine props (nominal size, 5-inch top by 6 feet long).

Species.	Reference No.	Moisture.	Approximate dry weight (volume as tested).	Rings per inch.	Summerwood.	Sapwood.	Diameter.		Crushing strength at maximum load.	Crushing strength at elastic limit.	Modulus of elasticity.	Remarks.
							Top.	Butt.				
Lodgepole pine (shipment A).	1	11.5	24.58	51	21	55	4.85	5.17	3,910	3,465	890	Grain spiral.
	2	11.4	24.46	43	22	58	4.77	5.57	3,992	3,580	875	
	3	11.2	27.96	57	18	33	5.17	5.57	4,770	4,190	1,194	
	4	12.3	24.16	34	20	68	5.09	5.57	3,340	2,750	954	
	5	11.0	25.83	47	19	35	4.77	5.25	4,640	3,580	1,031	
Av'ge.		11.5	25.40	46	20	50	4.93	5.43	4,130	3,513	993	
Lodgepole pine (shipment B).	6	11.0	28.14	43	26	42	4.38	5.01	5,100	4,110	1,198	Do.
	7	12.0	27.72	45	26	.....	5.25	5.57	6,340	4,980	1,450	
	8	15.9	23.42	50	26	61	5.17	5.49	4,980	4,010	1,135	
	9	11.2	29.52	45	20	37	4.01	5.73	6,190	4,750	1,452	
	10	11.1	26.58	42	17	37	5.25	5.41	5,230	4,240	1,175	
Av'ge.		12.2	27.08	45	23	44	4.81	5.44	5,568	4,438	1,282	
Alpine fir...	1	12.4	20.24	15	16		4.30	5.41	4,120	3,165	890	Do.
	2	12.0	22.88	23	12	.....	4.46	5.33	4,260	3,875	1,043	
	3	10.5	20.38	16	9	.....	4.06	5.09	3,910	3,550	1,002	
Av'ge.		11.6	21.17	18	12		4.27	5.28	4,097	3,530	978	
Engelmann spruce.	1	11.7	27.42	41	23		4.62	5.97	5,560	4,290	1,321	Do. Do. Do. Crooked. Grain spiral.
	2	11.2	28.10	25	13	.....	5.09	5.49	3,280	2,555	802	
	3	11.0	23.33	29	13	.....	3.50	4.62	3,742	3,120	1,021	
	4	13.0	24.00	43	22	.....	3.98	5.25	2,990	2,410	703	
	5	13.7	24.81	50	28	.....	4.30	4.93	4,540	3,850	1,196	
	6	11.3	23.86	31	20	.....	4.62	5.33	4,710	3,822	1,150	
	7	10.9	21.78	16	12	.....	4.85	5.49	4,030	3,030	1,098	
Av'ge.		11.8	24.76	33	19		4.42	5.29	4,122	3,297	1,042	
Douglas fir..	1	11.9	31.63	76	25	31	4.30	4.62	2,960	2,340	873	Crooked; grain spiral. Crooked; grain unusually knotty. Crooked; grain spiral. Grain slightly spiral, knotty.
	2	11.5	32.66	47	25	39	4.54	5.39	5,250	4,450	1,322	
	3	11.6	28.98	65	28	39	4.85	5.17	4,580	3,465	986	
	4	13.7	28.31	30	26	60	5.25	5.41	5,720	4,240	1,324	
	5	13.0	26.06	28	21	37	5.33	6.05	4,660	3,590	1,151	
Av'ge.		12.3	29.53	49	25	41	4.85	5.33	4,634	3,617	1,131	
Bristle-cone pine.	1	12.5	29.38	40	22	42	3.90	4.54	4,320	3,512	1,023	Crooked; grain spiral. Crooked.
	2	12.6	32.01	45	19	49	3.66	4.30	4,390	3,420	862	
	3	12.4	36.46	42	20	.....	3.66	4.22	3,042	2,280	837	
	4	12.2	30.34	35	19	68	3.18	4.30	2,340	2,013	628	
	5	12.2	25.37	30	20	.....	3.98	4.85	3,415	2,890	779	
Av'ge.		12.4	30.71	38	20		3.68	4.44	3,501	2,823	826	
Western yellow pine (shipment A).	1	10.5	21.48	16	17	21	3.66	4.80	3,050	2,470	742	Grain spiral.
	2	11.1	23.55	15	18	88	4.30	4.62	3,842	3,310	852	
	3	11.9	21.99	14	13	95	4.06	4.85	3,230	3,625	1,068	
	4	11.6	25.50	11	19	96	3.50	4.80	5,330	4,780	1,146	
	5	13.4	23.69	15	12	.....	4.14	4.85	3,370	2,822	626	
Av'ge.		11.7	23.24	14	16	75	3.93	4.78	3,764	3,401	887	
Western yellow pine (shipment B).	6	11.7	26.30	17	12		4.93	5.57	4,070	3,250	976	Crooked. Grain spiral. Do. Grain spiral, crooked.
	7	11.6	24.03	19	17	.....	4.70	5.25	4,260	3,690	863	
	8	13.0	27.72	31	20	.....	4.93	5.65	4,480	3,350	1,160	
	9	11.5	25.73	13	19	.....	4.93	5.41	4,790	3,770	1,115	
	10	10.9	23.64	12	14	.....	4.62	5.33	3,120	2,270	628	
Av'ge.		11.7	25.48	18	16		4.82	5.44	4,132	3,266	956	

TABLE 13.—Data on individual bending tests of green round mine caps (nominal size, 5-inch top by 8 feet long; span, 7 feet; third-point loading).

Species.	Refer- ence num- ber.	Moisture.	Approximate dry weight (volume as tested).	Rings per inch.	Sum- mer- wood.	Sap- wood.	Diameter.		Modulus of rupture.	Fiber stress at elastic limit.	Stiffness factor ($\frac{P}{\Delta}$)	Man- ner of failure. ¹	Remarks.
							Top.	Butt.					
Lodgepole pine (shipment A).....	1	Per cent.	Lbs. per cu. ft.		Per cent.	Per cent.	Inches.	Inches.	Lbs. per sq. in.	Lbs. per sq. in.			
	2	63.4	24.62	61	14	10	5.17	5.60	4,550	2,702	80.0	C.	
	3	77.3	25.43	44	11	49	5.63	6.00	4,040	3,930	88.0	T.	
	4	56.7	24.52	23	17	33	5.75	6.25	5,840	3,190	112.5	C.	
	5	106.1	24.03	40	23	58	5.42	6.38	4,690	2,635	95.2	C.	
	6	107.5	22.99	42	18	60	5.25	6.13	4,430	2,810	72.1	C.	
	7	87.5	21.07	44	23	69	5.75	6.50	4,830	3,315	85.5	T.	
	8	62.9	24.72	51	21	55	5.67	6.30	5,790	2,965	112.7	C.	Grain slightly spiral.
	9	129.8	24.23	56	22	77	5.60	6.12	5,460	3,250	115.4	C.	
	10	133.3	23.90	46	18	77	5.75	6.09	5,390	3,015	107.1	C.	
Average.....													
Lodgepole pine (shipment B).....		89.3	23.88	43	19	54	5.59	6.20	5,172	3,104	88.9		
	11	63.5	25.20	46	8	31	5.38	6.00	4,410	2,865	88.4	C.	
	12	40.1	26.31	36	10	37	5.95	6.70	5,900	3,555	124.4	C.	
	13	89.5	22.78	43	18	43	5.97	6.75	4,230	2,690	70.2	C.	
	14	64.8	25.51	52	18	50	5.75	6.00	6,180	3,530	126.2	C.	
	15	63.8	23.06	29	18	29	6.00	6.63	4,690	2,895	77.3	C.	Grain spiral.
	16	49.3	24.87	52	21	16	5.88	6.50	5,160	3,260	77.2	C.	
	17	62.6	24.09	43	22	54	6.00	6.75	5,340	2,215	92.5	C.	Do.
	18	48.0	20.89	31	12	54	5.75	6.63	3,585	2,235	55.3	T.	Do.
	19	82.7	22.12	47	15	72	5.25	6.00	4,470	2,730	85.3	C.	
Average.....													
Alpine fir.....		60.6	23.76	43	15	40	5.78	6.45	4,768	2,762	86.0		
	1	57.6	20.88	36	22	---	4.80	5.50	5,260	2,165	108.8	C.	Grain slightly spiral.
	2	68.1	20.38	19	14	---	5.63	6.50	3,030	2,150	82.5	T.	Do.
	3	109.8	21.54	34	13	14	5.00	5.88	4,880	2,802	89.6	C.	
	4	76.8	19.72	18	12	---	4.30	5.80	5,020	2,810	87.1	T.	
	5	90.7	20.79	23	16	---	4.50	5.50	4,270	2,910	73.1	T.	
	6	147.2	18.36	8	17	---	4.13	5.50	1,945	1,782	57.6	T.	
	7	146.1	16.57	9	17	---	4.40	5.58	4,160	1,970	70.9	T.	
	8	107.1	19.88	22	18	---	4.75	5.75	4,260	2,710	72.6	T.	
	9	92.3	17.94	20	14	---	4.38	5.38	4,310	2,755	71.2	T.	
Average.....													
Alpine fir.....		99.5	19.56	21	16	---	4.65	5.72	4,139	2,450	79.3		

		Do.										Do.										Do.																								
		C.					C.					C.					C.					C.					C.																			
		130.5					7,280					3,450					130.5					7,280					3,450					130.5					7,280					3,450				
Engelmann spruce.....		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40					
		1																																												

C indicates compression failure; T, tension failure.

TABLE 13.—Data on individual bending tests of green round mine caps (nominal size, 5-inch top by 8 feet long; span, 7 feet; third-point loading)—Continued.

Species.	Reference number.	Moisture.	Approximate dry weight (volume as tested).	Rings per inch.	Sum-mer-wood.	Sap-wood.	Diameter.		Modulus of rupture.	Fiber stress at elastic limit.	Stiffness factor $\left(\frac{F}{I_d}\right)$	Man-ner of failure. ¹	Remarks.
							Top.	Butt.					
Western yellow pine (shipment A).....		Per cent.	Lbs. per cu. ft.		Per cent.	Per cent.	Inches.	Inches.	Lbs. per sq. inch.	Lbs. per sq. inch.			
	1	83.3	19.42	12	14	.....	4.75	6.10	3,980	1,889	77.7	C.	
	2	89.5	21.30	12	16	.....	4.75	5.75	4,260	1,887	78.5	C.	
	3	88.8	21.63	13	13	19	4.38	5.70	4,060	2,695	84.8	T.	
	4	83.3	20.93	13	13	.....	4.25	5.82	4,050	2,114	81.8	C.	
	5	71.1	22.90	13	14	89	4.63	5.38	4,880	2,775	86.9	C.	
	6	105.6	22.83	15	13	93	3.88	4.75	4,260	2,205	71.1	C.	
	7	106.3	18.41	10	10	98	4.50	6.22	3,480	1,719	63.4	C.	
	8	73.4	21.20	14	11	94	4.20	5.42	4,530	2,095	82.3	C.	
	9	104.0	19.94	12	15	.....	4.80	5.85	3,860	1,553	59.1	C.	
	10,	79.7	19.72	14	17	.....	3.75	5.00	4,670	2,765	79.6	C.	
Average.....		88.5	20.92	13	14	.....	4.39	5.60	4,333	2,170	74.5		
Western yellow pine (shipment B)....													
	11	179.5	21.22	15	20	17	4.50	5.25	4,280	2,175	77.1	C.	
	12	143.9	22.01	30	13	.....	4.25	5.00	4,640	2,560	83.6	C.	
	13	155.2	23.68	22	12	92	4.63	5.50	6,190	3,500	87.1	C.	
	14	198.4	19.95	19	16	.....	3.02	5.25	5,150	3,025	66.2	C.	
	15	105.3	22.18	33	17	28	4.88	6.00	4,620	3,055	61.3	C.	
	16	86.5	22.78	42	22	28	4.38	6.12	3,320	2,148	35.9	T.	
	17	178.0	22.10	33	29	23	4.25	5.00	5,380	3,540	75.7	C.	
	18	140.7	23.48	15	10	.....	5.00	5.88	5,500	3,210	79.4	C.	
	19	113.5	24.03	34	14	27	4.50	5.50	4,980	3,165	80.8	C.	
	20	169.5	20.62	16	16	25	4.20	5.00	4,910	2,520	70.1	C.	
Average.....		147.1	22.20	26	17	.....	4.42	5.45	4,897	2,890	72.6		

¹ C indicates compression failure; T, tension failure.

TABLE 14.—Data on individual bending tests of air-seasoned round mine caps (nominal size, 5-inch top by 8 feet long; span, 7 feet; third-point loading).

Species.	Reference number.	Moisture.	Approximate dry weight (volume as tested).	Rings per inch.	Sum-mer-wood.	Sap-wood.	Diameter.		Modulus of rupture.	Fiber stress at elastic limit.	Stiffness factor $\left(\frac{P}{\Delta}\right)$	Man-ner of failure. ¹	Remarks.
							Top.	Butt.					
Lodgepole pine (shipment A).....		Per cent.	Lbs. per cu. ft.		Per cent.	Per cent.	Inches.	Inches.	Lbs. per sq. in.	Lbs. per sq. in.			
	1	11.9	26.22	61	18	39	4.62	5.09	8,240	6,080	119.5	T.	Grain spiral.
	2	11.3	26.17	33	10	37	4.54	5.09	9,440	7,170	138.2	C. T.	
	3	10.6	26.97	60	16	61	4.85	5.49	11,680	8,640	152.2	C. T.	
	4	11.5	25.07	44	17	29	4.70	5.33	7,180	4,790	129.7	T.	Do. Crooked.
	5	11.5	26.51	72	24	47	5.09	5.17	8,640	6,360	126.0	T.	
Average.....		11.4	26.18	54	17	43	4.76	5.21	9,026	6,600	133.1		
Lodgepole pine (shipment B).....													
	6	10.9	21.92	42	18	77	4.62	5.41	7,980	6,700	98.2	T.	Grain spiral.
	7	10.8	21.16	42	12	40	5.54	5.57	4,480	4,230	84.1	T.	
	8	11.7	27.02	44	16	38	5.41	5.33	9,020	7,290	148.2	T.	
	9	10.6	23.78	43	16	50	4.62	5.33	7,270	6,370	138.7	T.	Grain spiral.
	10	11.4	23.57	47	17	.....	5.01	5.41	5,410	5,220	103.2	T.	
Average.....		11.1	23.89	44	16	51	4.84	5.49	6,954	5,962	114.2		
Alpine fir.....													
	1	10.4	21.33	29	12	.....	4.62	5.25	8,790	6,600	125.2	T.	Unusually knotty. Grain spiral.
	2	11.4	20.46	22	9	.....	4.54	5.57	6,770	4,320	124.0	T.	
	3	11.4	20.17	20	19	.....	3.66	5.25	5,270	4,940	85.2	T.	
	4	12.1	22.32	37	15	.....	3.98	5.09	6,520	4,840	85.8	T.	Unusually knotty. Grain spiral.
	5	11.6	23.08	24	14	.....	4.30	5.25	9,350	6,600	122.1	T.	
Average.....		11.4	21.47	26	14	.....	4.22	5.28	7,340	5,460	108.5		
Englemann spruce.....													
	1	11.7	22.52	44	20	.....	5.33	6.05	6,260	5,190	103.5	T.	Grain spiral.
	2	11.8	27.50	45	20	.....	5.09	5.25	9,380	6,950	137.5	T.	
	3	11.5	27.49	37	18	.....	3.98	5.17	9,900	7,340	128.2	C. T.	
	4	10.6	26.02	27	9	.....	3.50	4.62	9,300	7,280	151.2	T.	Grain spiral.
	5	8.8	23.67	34	20	.....	4.14	5.65	6,370	6,330	72.0	T.	
Average.....		10.9	25.44	37	17	.....	4.41	5.35	8,242	6,618	118.5		

¹ C indicates compression failure; T, tension failure.

TABLE 14.—Data on individual bending tests of air-seasoned round mine caps (nominal size, 5-inch top by 8 feet long; span, 7 feet; third-point loading)—Continued.

Species.	Reference number.	Moisture.	Approximate dry weight (volume as tested).	Rings per inch.	Summer-wood.	Sap-wood.	Diameter.		Modulus of rupture.	Fiber stress at elastic limit.	Stiffness factor $\left(\frac{P}{Id}\right)$	Manner of failure. ¹	Remarks.
							Top.	Butt.					
Douglas fir.....	1	Per cent.	Lbs. per cu. ft.		Per cent.	Per cent.	Inches.	Inches.	Lbs. per sq. in.	Lbs. per sq. in.			Grain spiral.
	2	11.4	27.87	22	28	64	4.30	5.17	10,080	6,970	121.8	T.	Do.
	3	12.3	29.48	29	23	54	4.77	5.41	10,030	7,180	145.1	T.	Do.
	4	11.6	26.31	15	14	74	4.62	5.57	10,960	7,300	129.3	C. T.	Do.
	5	12.2	26.59	25	22	46	3.82	5.09	5,790	5,100	92.3	T.	Do.
Average.....		11.5	26.36	26	21	44	3.98	4.77	8,700	7,660	142.5		
		11.8	27.92	23	22	56	4.30	5.20	9,232	6,842	126.3		
Bristle-cone pine.....	1	12.5	26.43	52	14	38	4.22	5.09	9,210	5,420	103.8	T.	Grain spiral, unusually knotty.
	2	10.7	29.31	32	.....	55	3.66	4.54	7,320	6,700	116.1	T.	Grain spiral.
	3	10.9	32.63	33	15	63	3.82	5.09	8,960	5,800	90.0	T.	Crooked.
	4	12.0	32.52	40	10	62	3.90	5.25	7,000	4,120	88.5	T.	
	5	11.6	31.63	27	18	74	3.50	4.93	9,550	6,380	98.5	C. T.	
Average.....		11.5	30.46	37	14	58	3.82	4.98	8,408	5,684	97.7		
	1	10.5	22.62	14	11	93	3.66	5.09	7,980	6,020	96.3	T.	
	2	10.2	24.93	15	13	.....	3.88	4.77	8,580	6,380	115.7	T.	
	3	10.6	24.65	15	12	.....	3.65	4.70	9,730	7,730	118.2	T.	
	4	10.4	21.28	13	10	.....	3.50	5.09	7,060	4,850	87.5	C. T.	
Average.....		9.4	22.22	15	12	.....	3.50	4.62	5,660	3,870	101.5	T.	Grain spiral.
		10.3	23.14	14	12	.....	3.58	4.85	7,660	5,770	103.8		
Western yellow pine (shipment B).....	6	11.4	25.63	26	8	93	3.82	5.25	6,330	5,830	76.8	T.	Crooked.
	7	10.4	24.54	21	17	95	3.90	5.33	4,210	4,220	75.0	T.	Unusually knotty.
	8	10.8	24.77	17	20	.....	4.22	5.41	5,380	4,600	62.2	T.	
	9	10.5	24.46	23	11	97	3.58	4.62	6,780	5,470	112.6	T.	
	10	10.3	22.66	18	17	.....	3.98	5.01	7,360	4,570	73.5	T.	
Average.....		10.7	24.41	21	15	.....	3.90	5.12	6,012	4,938	80.0		

¹ C indicates compression failure; T, tension failure.

TABLE 15.—Data on individual bending tests of green round beams (16 feet long; span, 15 feet; third-point loading).

Species and size.	Ref. No.	Moisture.	Approximate dry weight (volume as tested).	Rings per inch.	Summer-wood.	Sap-wood.	Diameter.		Modulus of rupture.	Fiber stress at elastic limit.	Stiffness factor $\left(\frac{P}{l^3}\right)$	Work to maximum load.	Manner of failure. ¹	Remarks.
							Top.	Butt.						
Lodgepole pine cut from live timber: 8-inch butt.	1	Per cent.	Lbs. per cu. ft.		Per cent.	Per cent.	Inches.	Inches.	Lbs. per sq. in.	Lbs. per sq. in.		Inch lbs. per cu. in.		
	2	84.0	21.96	37	18	.....	6.53	7.76	2,425	3.0	11.71	3.0	C.	
	3	66.5	20.03	34	18	.....	6.81	8.13	5,060	6.3	10.65	6.3	C.	
	4	80.6	23.32	28	18	.....	7.24	8.44	5,210	4.4	10.10	4.4	C.	
	5	77.7	23.22	31	23	49	7.54	8.28	5,040	2,895	10.71	5.0	C.	
	6	80.2	24.44	29	23	49	7.52	8.59	5,770	3,315	13.42	6.6	C.T.	
	7	80.4	24.04	32	14	65	6.76	8.75	5,510	4,200	12.01	2.6	C.T.	
	8	75.5	24.56	33	15	59	6.53	8.04	4,860	2,581	9.26	4.8	C.	Grain spiral.
	9	66.1	23.71	31	14	43	6.92	8.20	5,270	3,135	11.10	4.8	C.	Do.
	10	62.1	23.53	35	22	41	6.68	7.88	4,860	3,010	10.42	5.1	C.	
Average		77.3	23.40	32	18	51	6.77	8.20	5,348	3,120	10.99	4.7		
	11	95.7	23.78	25	16	44	8.20	9.71	4,510	2,870	9.70	5.3	C.T.	
	12	113.0	23.28	26	21	71	8.44	9.47	5,020	3,205	11.36	3.2	C.T.	
	13	97.5	25.63	24	19	.....	8.59	10.03	5,810	3,905	11.73	4.9	C.	
	14	73.4	22.38	32	13	.....	7.24	9.39	4,900	2,038	7.48	3.8	C.	Grain spiral.
	15	82.2	22.58	28	16	46	8.44	10.27	4,980	2,770	10.38	5.2	C.	
	16	88.5	22.78	31	21	51	7.72	9.87	5,380	3,170	9.87	6.4	C.	
	17	94.5	23.15	26	21	51	9.63	10.74	4,646	2,320	10.72	6.0	C.	
	18	73.8	23.48	26	17	59	7.88	9.95	6,230	3,510	10.96	7.7	C.	
	19	87.2	24.19	28	21	56	8.04	9.71	5,590	3,395	9.46	4.3	C.T.	
Average		118.2	21.44	21	21	79	8.44	10.51	5,270	2,900	11.52	7.8	C.	
	20	90.2	23.27	27	19	58	8.26	9.97	5,233	3,008	10.32	5.5		
	21	99.1	22.44	18	22	67	10.82	12.09	6,270	3,750	9.81	6.2	C.T.	
	22	99.6	21.63	23	27	71	10.11	11.55	5,790	3,750	13.70	5.4	C.	
	23	96.0	23.62	22	27	65	10.03	11.46	5,070	2,592	8.16	5.6	C.	
	24	81.6	27.56	24	21	.....	9.39	10.98	5,650	2,650	11.48	6.1	C.	
	25	96.3	22.53	24	13	65	9.87	11.46	4,440	2,298	8.84	7.0	C.	
	26	98.2	20.06	23	24	52	10.11	11.30	4,730	2,970	10.06	6.6	C.	
	27	94.0	21.35	24	17	.....	9.23	11.85	4,880	3,438	11.42	3.1	C.T.	
	28	78.3	20.23	23	11	47	9.39	11.54	4,230	2,560	9.05	2.0	C.T.	Do.
Average		92.5	24.09	23	17	65	9.39	11.30	4,870	2,880	10.13	6.1	C.	Do.
	29	82.5	22.12	24	16	38	9.87	12.41	5,070	2,940	9.60	4.4	C.T.	
	30	91.8	22.56	23	19	59	9.82	11.62	5,095	2,987	10.23	5.2		

1 C indicates compression failure; T, tension failure.

 Crooked and unusually knotty.
Grain spiral.

TABLE 15.—Data on individual bending tests of green round beams (16 feet long; span, 15 feet; third-point loading)—Continued.

Species and size.	Ref. No.	Moisture.	Approximate dry weight (volume as tested).	Rings per inch.	Sum-mer-wood.	Sap-wood.	Diameter.		Modu-lus of rup-ture.	Fiber stress at elastic limit.	Stiff-ness factor $\left(\frac{1}{I\Delta}\right)$	Work to factor maximum load.	Manner of failure.	Remarks.
Lodgepole pine (fire killed; water soaked, cut from timber after standing dead for 30 years; 8-inch butt.)	1	Per cent.	Lbs. per cu. ft.		Per cent.	Per cent.	Inches.	Inches.	Lbs. per sq. in.	Lbs. per sq. in.		Inch lbs. per cu. in.	T.	Grain spiral.
	2	39.0	24.67	48	21	30	6.92	9.06	5,770	3,690	9.48	4.4	T.	Do.
	3	35.0	26.72	48	17	28	7.08	8.83	5,560	2,670	8.90	4.9	T.	Do.
	4	45.2	25.49	52	16	21	6.92	8.28	3,570	2,210	8.00	2.8	C. T.	Do.
	5	35.0	27.38	34	17	26	7.00	8.52	6,580	2,935	13.25	7.6	C. T.	Do.
Average		38.1	26.02	44	18	30	7.00	8.50	5,448	2,905	10.38	5.3		
10-inch butt.	6	31.4	27.61	48	22	19	7.56	9.88	6,500	4,180	10.97	5.4	C. T.	Do.
	7	45.9	21.62	42	20	20	8.12	10.19	5,020	2,805	10.62	3.7	C. T.	Do.
	8	45.5	22.70	36	19	31	8.36	10.27	3,870	1,592	7.09	4.0	C. T.	Do.
	9	29.8	24.65	37	14	.....	7.80	9.71	4,560	2,585	7.38	2.4	C. T.	Do.
	10	47.7	23.67	35	20	36	9.23	11.14	4,750	3,590	8.13	1.6	C.	
Average		40.1	24.05	40	20	.....	8.21	10.24	4,940	2,950	8.84	3.4		
12-inch butt.	11	27.8	25.32	24	20	.....	10.11	12.01	3,925	1,862	6.36	3.3	T.	Do.
	12	41.7	23.23	27	15	20	10.11	12.89	4,497	2,605	9.18	2.0	T.	Do.
	13	38.9	22.32	29	16	15	10.98	12.97	4,230	2,345	8.13	2.8	C. T.	Do.
	14	36.3	26.13	26	17	25	9.47	11.77	5,680	2,960	9.71	8.2	C. T.	Do.
	15	41.2	23.33	34	13	19	9.31	12.73	3,820	1,828	5.18	5.3	C.	Do.
Average		37.2	24.06	28	16	20	10.00	12.47	4,430	2,320	7.71	4.3		

1 C indicates compression failure; T, tension failure.

TABLE 16.—Data on individual bending tests of air-seasoned round beams (16 feet long; span, 15 feet; third-point loading).

Species and size.	Ref. No.	Moisture.	Approximate dry weight (volume measured as tested).	Rings per inch.	Summation of wood.	Sapwood.	Diameter.		Modulus of rupture.	Fiber stress at elastic limit.	Stiffness factor ($\frac{P}{l^3}$)	Work to maximum load.	Manner of failure. ¹	Remarks.
							Top.	Butt.						
Lodgepole pine cut from live timber: 8-inch butt.		Per cent.	Lbs. per cu. ft.		Per cent.	Per cent.	Inches.	Inches.	Lbs. per sq. in.	Lbs. per sq. in.	Inches.	Inches.		
	1	17.0	28.46	29	19	50	7.64	8.36	7,840	4,640	14.24	4.9	C. T.	Grain spiral.
	2	19.9	25.33	32	23	.....	6.37	7.80	7,220	4,980	12.43	4.2	C. T.	Do.
	3	15.2	24.78	33	20	60	6.84	8.04	7,160	5,290	12.71	3.1	C. T.	Do.
	4	16.5	26.75	23	34	60	6.61	7.64	9,310	5,050	14.09	4.1	C. T.	Do.
	5	15.4	27.08	33	26	67	7.48	8.36	7,210	5,130	16.80	2.7	T.	Do.
	Average	16.8	26.60	32	22	61	6.99	8.04	7,748	5,018	14.05	3.8		
	6	14.6	25.80	27	28	71	7.08	9.55	9,000	5,940	18.75	4.0	C. T.	Wide checks.
	7	18.3	23.08	24	20	42	8.28	9.71	6,810	4,860	11.97	3.0	T.	At ax cut, badly checked.
	8	17.6	24.87	26	28	.....	8.08	9.55	7,260	5,310	14.38	3.8	C. T.	Grain slightly spiral.
Average	9	18.1	27.98	23	28	64	8.42	10.03	7,130	4,780	10.31	3.3	C. T.	Grain spiral.
	10	16.9	23.18	24	19	57	8.59	10.03	4,480	3,190	11.27	1.5	T.	
	Average	17.1	25.10	25	24	59	8.09	9.77	6,948	4,816	13.33	3.1		
	11	21.8	23.65	23	20	55	9.71	11.30	5,310	3,530	9.05	2.7	C. T.	Grain spiral, 4 knots in plane of failure.
	12	19.9	22.02	23	25	49	9.55	11.77	3,745	2,875	6.85	1.2	T.	Grain spiral.
	13	17.9	19.77	23	26	62	9.31	10.82	5,860	4,550	11.16	2.1	T.	
	14	19.1	25.55	22	22	61	9.95	11.14	6,350	4,340	11.62	3.0	T.	
	15	17.7	25.42	21	21	53	9.71	11.81	6,230	4,220	10.75	2.5	T.	Crooked and unusually knotty.
	Average	19.3	23.28	22	21	56	9.73	11.51	5,409	3,741	9.57	2.3		
Lodgepole pine (fire killed) cut from timber after standing dead for 30 years: 8-inch butt.														
	1	11.5	25.00	45	15	22	6.08	7.48	3,843	3,195	9.64	1.4	T.	Grain slightly spiral.
	2	14.5	26.49	45	18	13	7.16	8.12	7,780	5,390	11.43	5.6	C. T.	Do.
	3	12.9	25.96	39	15	36	7.08	8.59	6,390	3,850	10.95	2.4	C. T.	Do.
	4	14.6	24.66	17	17	12	7.16	8.91	5,310	4,910	9.58	1.7	T.	Do.
	5	12.4	24.93	37	12	30	6.45	8.59	4,190	3,880	9.98	.8	T.	Do.
	6	13.3	25.48	51	17	42	6.53	7.88	5,850	4,660	11.83	2.2	T.	Do.
	7	13.4	25.80	36	17	20	7.16	8.59	6,940	4,720	12.51	2.3	T.	Grain slightly spiral, crooked.
	8	12.8	27.17	36	17	14	7.64	8.59	5,995	4,020	12.23	1.8	T.	Grain spiral.
	9	11.7	25.49	34	20	.....	6.92	8.75	4,330	4,190	10.17	1.0	T.	Do.
	Average	13.7	25.66	40	16	24	6.98	8.39	5,625	4,649	10.92	2.1		

¹ C indicates compression failure; T, tension failure.

TABLE 16.—Data on individual bending tests of air-seasoned round beams (16 feet long; span, 15 feet; third-point loading)—Continued.

Species and size.	Ref. No.	Moisture.	Approximate dry weight (volume as tested).	Rings per inch.	Summer-wood.	Sap-wood.	Diameter.		Modulus of rupture.	Fiber stress at elastic limit.	Stiffness factor ($\frac{P}{\Delta}$)	Work to maximum load.	Manner of failure. ¹	Remarks.
							Top.	Butt.						
Lodge-pole pine (fire killed) cut from timber after standing dead for 30 years—Con. 10-inch butt.		Per cent.	Lbs. per cu. ft.		Per cent.	Per cent.	Inches.	Inches.	Lbs. per sq. in.	Lbs. per sq. in.		Inch lbs. per cu. in.		
	10	14.4	26.36	42	20	36	8.20	9.31	7,350	5,570	10.85	3.4	C. T.	Grain spiral.
	11	13.3	27.23	39	17	19	7.64	10.03	6,840	4,060	8.06	3.4	T.	Do.
	12	12.7	24.62	24	15	26	7.88	10.35	8,370	6,400	13.26	4.2	T.	Unusually knotty.
	13	12.4	21.43	40	11	25	8.75	10.43	2,690	2,585	9.77	.5	T.	Grain spiral.
	14	12.1	25.00	36	14	21	7.64	10.03	3,165	2,870	9.35	.8	T.	Grain spiral, crooked, unusually knotty.
	15	12.6	24.67	26	13	33	8.91	10.51	4,820	4,660	10.53	1.5	T.	Grain slightly spiral.
	16	12.4	27.03	32	14	21	8.28	10.66	6,350	5,280	9.28	2.8	T.	Grain slightly spiral, knotty.
	17	12.6	.....	26	14	17	8.67	9.87	5,650	3,800	11.46	1.6	T.	Grain spiral.
	18	13.4	27.63	35	14	19	8.28	10.03	6,610	5,030	9.33	3.4	T.	Grain slightly spiral.
	19	13.2	23.58	42	17	22	8.44	9.87	5,210	4,630	13.53	1.4	T.	Grain slightly spiral.
	Average	12.9	25.28	34	15	24	8.27	10.11	5,166	4,489	10.54	2.3		
	20	12.4	28.20	29	19	15	9.15	11.46	7,310	5,960	12.29	3.8	T.	Grain spiral, apparently rotten, badly checked.
	21	13.4	25.03	24	15	36	9.55	12.06	2,060	1,343	8.12	.4	T.	Apparently rotten and unusually knotty.
	22	12.1	24.39	31	14	24	9.23	12.17	3,452	3,235	8.17	.7	T.	Grain spiral, unusually knotty.
	23	13.0	28.46	32	16	31	9.07	12.33	5,070	4,350	8.79	1.8	T.	Grain spiral, unusually knotty.
	24	15.3	26.26	29	17	31	10.98	12.49	5,700	3,810	9.34	2.9	T.	Do.
	25	12.0	24.87	37	14	20	9.15	11.54	4,740	4,440	10.11	1.4	T.	Do.
	26	13.8	23.79	32	18	15	9.55	12.25	6,090	5,070	10.41	2.6	T.	Do.
	27	12.3	26.43	30	13	14	10.19	12.41	4,880	4,480	11.53	1.6	T.	Do.
	28	16.3	26.15	29	16	13	11.14	12.49	4,445	3,135	9.73	1.9	T.	Do.
	29	14.6	24.53	37	8	21	9.95	12.30	4,410	3,665	10.33	1.4	T.	Grain spiral, knotty, and crooked.
	30	16.6	27.03	31	13	16	9.39	12.09	4,760	3,670	9.63	1.6	T.	
Average		13.8	26.46	31	15	22	9.16	12.15	4,720	3,925	9.84	1.7		

¹ C indicates compression failure; T, tension failure.

MANNER OF FAILURE.

The prop failures were quite uniform. Compression wrinkles occurred usually through one or more knots and, if the prop had a slight bend in it, the wrinkles were on the concave side at the point of greatest eccentricity. If this bend were at all prominent, tension often occurred and in several instances the prop separated in two parts as in the brittle cap failure. The influence of checks on the form of failures was quite noticeable in the dry props, the shortening of the props giving the check, if spiral, the appearance of "unwinding" as in the strands of a rope. Figure 6 shows this effect to some extent.

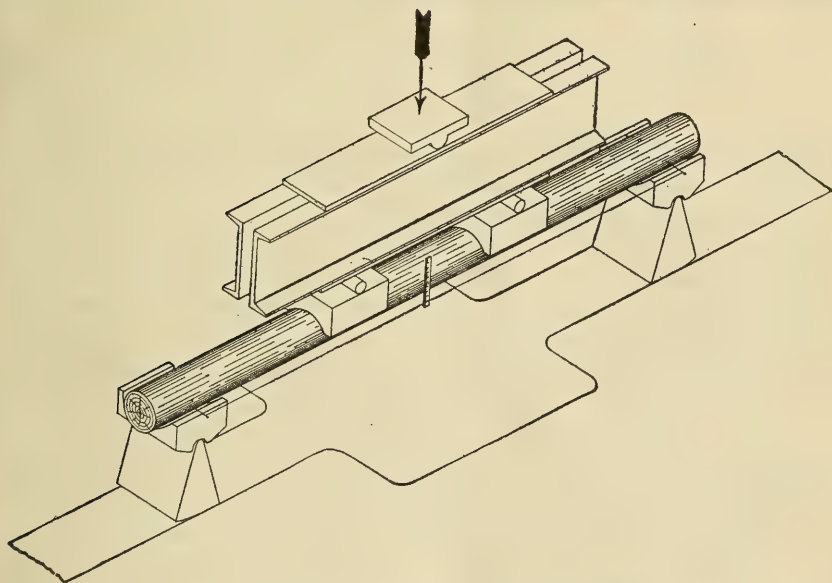


FIG. 7.—Method used in testing mine caps in bending.

CAPS.

The failures of the green caps were quite uniform in character among the various species. Near or at the maximum load, compression took place on the upper surface between the loading points. The load fell off slowly, and if continued, failure by tension ultimately took place. The green Alpine fir caps, however, had a larger proportion of tension than compression failures, and the Douglas fir had approximately the same number of each.

The dry caps, as far as could be detected by the eye, generally failed in tension near the center. Occasionally compression wrinkles occurred, but the failures were more often sudden, and some indicated brittle material. There was no material difference in the failure of the different species. In the dry material the tension splinters often ended at a check, but it was not apparent that the type of failure or

strength of the specimen was definitely influenced by the seasoning cracks, even when more or less spiral.

BEAMS.

The beam failures were similar to those occurring in the caps. The water-soaked material failed almost entirely in compression on the upper surface, the failure wrinkles becoming visible shortly before the maximum load was reached. Some of the green beams had a very large deflection, and the stress-strain curves were typically somewhat flat topped. The dry beams failed in tension, sometimes accompanied by failure in compression.





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(PROFESSIONAL PAPER.)

THE SO-CALLED TOBACCO WIREWORM IN VIRGINIA.¹

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INTRODUCTION.

For the study of insects injurious to tobacco the Bureau of Entomology during the last four summers has maintained a temporary field station at Appomattox, Va. Work of this station has been under the direction of Mr. W. D. Hunter, in Charge of Southern Field Crop Insect Investigations, and more immediately under the supervision of Mr. A. C. Morgan. Laboratory quarters were furnished by the Tenth Congressional District Agricultural School. The results of investigations of the tobacco Crambus (*Crambus caliginosellus* Clem.) are given in this bulletin.

The work in Virginia was in cooperation with the State experiment station and the Bureau of Plant Industry of the U. S. Department of Agriculture. Through an agreement with the cooperators, the Bureau of Entomology was furnished all data pertaining to the rotation of crops grown in connection with tobacco, and the plats of the several tobacco stations in the State were placed at the disposal of the agent in charge, for inspection and experiment. The records of these stations, extending over a series of years, are of great value in determining the crop rotations and cultural methods of control best adapted to the special conditions to be dealt with in different tobacco sections.

The experimental work with tobacco in Appomattox County, Va., was begun by the Bureau of Soils in 1904. The work has since been conducted cooperatively by the Bureau of Plant Industry and the Virginia experiment station. Since the first, owing to the work of

¹ Throughout the tobacco-growing sections of Maryland, North Carolina, and Virginia the larvæ of the tobacco Crambus are generally known as "wireworms." They are also known in other sections as "tobacco wireworms," "budworms," "corn worms," "stalk worms," "heart worms," "entworms," "stem worms," "root webworms," and "screw worms." In parts of Tennessee and Kentucky the larvæ are commonly called "screw worms." The term "wireworm" is also applied, as in other sections, to the true wireworms (larvæ of Elateridæ), which the Crambus larvæ in no way resemble.

NOTE.—This bulletin is descriptive of an insect enemy of tobacco and corn. Of especial interest in the eastern tobacco and corn districts.

the tobacco Crambus, great difficulty has been encountered, in many of the experiments, in getting the perfect stand of plants so essential for comparative tests. This led to a study of the life history of the insect and of the somewhat extensive cultural experiments by the Bureau of Entomology aimed at its control. The effect of certain crop rotations in reducing injury from the tobacco Crambus was noticed during the early progress of the cultural investigations by Mr. E. H. Mathewson, Crop Technologist of the Bureau of Plant Industry, to whom the writer is indebted for suggestions concerning the cultural methods of control undertaken by the Bureau of Entomology.

GENERAL HABITS AND ECONOMIC IMPORTANCE OF THE GROUP TO WHICH THE TOBACCO CRAMBUS BELONGS.

The larvæ of insects included in the family Crambidae, to which the tobacco Crambus belongs, feed mainly on the grasses (Gramineæ), although some of them subsist on plants of other families. Many construct tubular, web-lined galleries near the roots of the plants on which they feed, and some bore or tunnel into the roots or stems; for this reason they have been named "root webworms." The moths, or adults, are medium or rather small in size, with brown, yellow, or white colors prevailing. Many species have metallic markings on the forewings, which are comparatively long and usually narrow. When at rest the forewings are rolled around the body and conceal the hind wings, which are folded beneath. This gives the body the appearance of a tiny cylinder, and accounts for the term "close-wings." The species are widely distributed over the globe, but are apparently most numerous in temperate climates. In North America comparatively few are known, and the majority of these belong to the genus Crambus, in which Dr. H. G. Dyar¹ catalogues 60 species.

Moths of the genus Crambus fly mostly on dark afternoons and during the early part of the night. They are more common in open fields. When disturbed they make short erratic flights, rarely flying more than a few rods at a time. They usually alight head downward on the stems of plants, and their color often harmonizes so perfectly with their surroundings that they can with difficulty be seen. Most of the species are single-brooded; but as the moths of different species emerge successively throughout the season, one or more of the latter are present in most localities from spring until late fall. Though various species of Crambus are common in most localities, they seldom attract much attention unless some important crop is attacked. This is due (1) to the fact that the moths are small and inconspicuous, (2) to the underground feeding habits of the arvæ, and (3) to the fact that damage from different species is distributed throughout the growing season.

¹ Dyar, Harrison G. A List of North American Lepidoptera * * *. U. S. Nat. Mus. Bul. 52, pp. 404-410, 1902.

The principal species of the genus of economic importance in this country are: *Crambus caliginosellus* Clemens, which attacks tobacco and corn; *C. vulgivagellus* Clemens, an enemy of corn, wheat, rye, and grasses; *C. trisectus* Walker, an enemy of grasses, oats, and corn; *C. laqueatellus* Clemens, which attacks corn and oats; *C. zeellus* Fernald, *C. luteolellus* Clemens, and *C. mutabilis* Clemens, enemies of corn; and *C. hortuellus* Hübner, which is injurious to the cranberry. The wide distribution of several of these and their great capacity for injury give them rank as species of considerable economic importance. Damage by them to cultivated crops is, in most cases, the result of unusual conditions. Their range of food plants is not large, and the larvæ are inclined to remain in or near one place. The moths frequent the weedy fields, pastures, or meadows which contain the natural food plants of the larvæ, and the greater number of eggs are deposited in such localities. When such land is plowed up the larvæ are forced to live on other than their natural food plants. With crops such as corn and tobacco this means a concentration of larvæ from many of the wild or natural food plants to the comparatively few cultivated plants.

ECONOMIC IMPORTANCE OF THE TOBACCO CRAMBUS.

The tobacco Crambus (*Crambus caliginosellus* Clem.) occurs in most, if not all, of the tobacco-growing districts of the Eastern States, but it seems to be most destructive in certain sections of Maryland and Virginia. It is especially destructive in the famous "dark-tobacco district" of the Piedmont section of middle Virginia, although found in all sections of the State in which tobacco is grown. In Virginia the damage to the tobacco crop alone from the insect is estimated to average at least \$800,000 annually.

At the Virginia tobacco experiment stations, at Appomattox, Bowling Green, and Chatham, injury has been recorded for a number of years. The reduction in value of the crop has been great, amounting to about 14 per cent annually, through failure to secure an early stand of plants. At the Appomattox Station, in one of the experimental fields, there was a loss in 1910 amounting to about 27 per cent. In 1911 there was still greater loss in some of the plats. In many fields in the county fully one-half of the plants were attacked, making several replantings necessary. At the Chatham Station in 1909 there was an estimated decrease in the value of the crop amounting to about \$15 per acre.

In 1912 considerable damage occurred to tobacco in Montgomery County, Tenn., and in Christian and Todd Counties, on the southern border of Kentucky, growers in a number of instances reporting fully 40 per cent of the plants destroyed.

The insect has for many years been a serious pest to tobacco and corn in Maryland. W. G. Johnson, formerly State entomologist, recorded the species as extremely abundant and destructive in Prince Georges, Cecil, Kent, Queen Anne, and Dorchester Counties in 1897, and reported damage in various parts of the State in 1898, 1899, and 1900, many fields of young corn being almost completely destroyed.

M. H. Beckwith mentions it as injurious to corn in Delaware, and John B. Smith has recorded injury to corn in New Jersey.

ORIGIN AND DISTRIBUTION.

Crambus caliginosellus has been recorded only from North America. Its preference for the naturalized buckhorn plantain and ox-eye daisy as food plants, however, points to the possibility that it has been introduced from Europe.

In literature the recorded distribution of the species is as follows: Ontario (Saunders, Felt, and Fernald); New York (Grote, Felt, and Fernald); Delaware (Beckwith); New Jersey (Smith); Maryland (Johnson and Howard); Massachusetts, Pennsylvania, District of Columbia, North Carolina, Illinois, and Texas (Fernald); Virginia (Mathewson, Anderson, and Runner); Ohio (Gossard).



FIG. 1.—Adult, or moth, stage of the tobacco Crambus, or "wireworm" (*Crambus caliginosellus*). Enlarged. (Original.)

In collections in the National Museum are specimens from the following localities: Washington, D. C. (August Busck); Plummers Island, Md. (H. S. Barber); Plainfield, N. J. (F. O. Herring); Pittsburgh, Pa. (H. Engel); Clarksville, Tenn. (A. C. Morgan); Chapel Hill, Tenn. (G. G. Ainslie); Vienna, Va. (R. A. Cushman).

Records of the Bureau of Entomology show the insect to be present in Pennsylvania, Delaware, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Ohio, Tennessee, and Kentucky.

These records indicate a wide distribution, but as most reports of injury to cultivated crops come from certain portions of the Eastern States it is probable that severe injury occurs only in localities where natural food plants are exceedingly abundant, and where crops subject to injury are planted at the time the larvæ are completing their growth and are in their most active feeding stage.

SEASONAL HISTORY.

The moths (fig. 1) emerge during summer, the heaviest emergence occurring at Appomattox, in central Virginia, during the first and second weeks in August. The earliest emergence takes place during

the latter part of June, but moths are not abundant until about the third week in July. From this time their numbers gradually increase until about the second week in August, when they are exceedingly numerous, at times appearing almost in swarms in weedy fields when disturbed. From the middle of August there is a rapid decrease and after the 1st of September only an occasional one can be found. Table I gives dates of emergence of moths from some of the field cages at Appomattox in 1910.

TABLE I.—*Emergence of moths of the tobacco Crambus in outdoor rearing cages at Appomattox, Va., 1910.*

Larvæ collected—	Food plant on which found.	Moth emerged—	Larvæ collected—	Food plant on which found.	Moth emerged—
1910.		1910.	1910.		1910.
June 4.....	Tobacco.....	July 2.....	June 26.....	Tobacco.....	July 18.....
Do.....	do.....	July 21.....	Do.....	Wild carrot.....	Aug. 13.....
Do.....	do.....	July 22.....	Tobacco.....	Aug. 6.....	Aug. 6.....
Do.....	do.....	Aug. 3.....	Do.....	do.....	Aug. 15.....
June 5.....	do.....	July 3.....	June 28.....	Plantain.....	July 14.....
Do.....	Corn.....	July 14.....	Do.....	Daisy.....	Aug. 15.....
Do.....	Senecio.....	July 22.....	Do.....	Aster (stickweed).....	Aug. 7.....
Do.....	Plantain.....	July 23.....	July 1.....	Plantain.....	July 29.....
June 6.....	Corn.....	July 26.....	Do.....	Tobacco.....	Aug. 14.....
Do.....	Daisy.....	Aug. 1.....	Do.....	Corn.....	July 27.....
Do.....	Aster spp.....	July 29.....			

The females die soon after egg laying is finished. There is apparently only one generation a year, the eggs hatching in summer and the larvæ completing their growth during the following year. The greater number of larvæ are in the pupal stage during the first half of July.

DESCRIPTION.

THE EGG.

The egg (fig. 2) is creamy white when first deposited, but gradually assumes a pinkish shade, which deepens to orange rufous before hatching. The average length is 4 mm. and the diameter 0.32 mm. It is regularly oval, with the ends slightly truncate, and has a polished appearance. There are about 18 longitudinal carinæ and numerous transverse striæ.



FIG. 2.—The tobacco Crambus: Egg. Greatly enlarged. (Original.)

THE LARVA.

FIRST INSTAR.

When first hatched, the body of the larva is semitransparent, and the alimentary canal can be plainly seen. The outline of the body, when seen from above, is almost triangular. The larva is white, or pale yellowish white, and about 1 mm. long, with a few scattered, light-colored hairs on the head and body. The head shield measures 0.15 mm. in width, is yellowish brown, and moderately bilobed, with the clypeus attaining the apical third. The cervical shield is tinged slightly with brownish. Five pairs of prolegs occur on the 7th to 10th segments, inclusive, and on the 13th segment.

LAST INSTAR.

The full-grown larva (figs. 3, 4) is about 15 mm. long, and yellowish white, with a tinge of pink dorsally. The hairs of the body are slender, brownish, and set on large fuscous tubercles. The head shield measures 1.2 mm. in width, and is pale yellowish

brown, flecked with darker brown. The cervical shield is distinct, shining, yellowish brown, tinged with fuscous, and bears 12 hairs in two transverse equal rows. The anal shield is pale fuscous. About the middle of abdominal segments 3, 4, 5, and 6, and slightly above the spiracles, is a series of distinct, dark fuscous, chitinous areas about the size and shape of spiracles, one to each segment.

The arrangement of the tubercles is as follows: Beneath the anterior margin of the cervical shield is a tubercle bearing two hairs. The mesothorax above bears eight

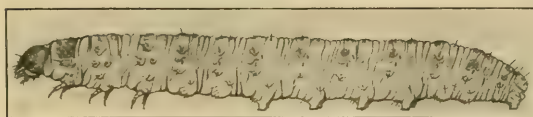


FIG. 3.—The tobacco Crambus: Full-grown larva, or "wireworm."
Much enlarged. (Original.)

setigerous tubercles on the anterior margin, each, except the lateral tubercle, with two hairs. Posteriorly it is provided with three bare tubercles, of which the median is narrow and transverse. The metathorax is armed, as is the mesothorax. Each abdominal segment above the spiracles bears two transverse rows of four tubercles each. The anterior dorsal pair are subquadrate, with the posterior lateral angles strongly rounded. The posterior dorsal pair are oblong, transverse, about half as long as the anterior, with the posterior lateral angles strongly rounded. The anterior lateral tubercles are supraspiracular, irregularly quadrate, with the lower margin produced diagonally behind the spiracle, emarginate at the spiracle and before the impressed area on segments 3, 4, 5, and 6. The corresponding tubercle on segment 8 has the produced portion isolated and is placed anterior to the spiracle. The posterior lateral tubercles are transverse, elongate, and somewhat oblique.

Abdominal segments 1 to 7 each bear a minute spinule anterior to and nearly equidistant from the spiracle and the supraspiracular hair.

The legs are pale brown, the maxillary palpi brown, and the mandibles brownish fuscous at apices.

The color of larvæ collected from different food plants varies considerably, this being merely an effect of the color, whether light or dark, of the food in the alimentary canal. Larvæ collected from corn are considerably lighter than those collected from tobacco.



FIG. 4.—The tobacco Crambus: Head of larva. Greatly enlarged. (Original.)

THE PUPA.

The pupa (fig. 5) measures about 8 mm. in length and 2 mm. in greatest width. The general color is dark brown, or pale yellowish brown when newly transformed, with the appendages and segments marked with dark brown. The head is blunt, with a median apical emargination. The tips of the wings are rounding on abdominal segment 5; the margin of the inner wing is visible over segments 2, 3, and 4. The spiracles are not prominent, the first three pairs being set on blunt tubercles. The cremaster is transversely rounded oblong, with a lateral bristle near the apex.

THE ADULT, OR MOTH.

Expanse of wing, 13–25 mm. Head, palpi, and thorax dark fuscous, sprinkled with gray scales. Fore wing dark fuscous, sprinkled with brown or yellowish, and frequently with a few gray scales; median line dark brown, often edged with white, aris-

ing a little beyond the middle of the costa, extending outward, forming a very acute angle, thence backward across the end of the cell to the hind margin, a little beyond the middle, and giving off an outward angle on the fold. Subterminal line dark brown, edged outwardly with dark lead-colored scales, and frequently dentate along the first part of its course. It arises from the costa about half way between the median line and the apex, extending down to a point beyond the end of the cell, where it forms an outward angle, thence to the hind margin, a little within the anal angle, giving off an inward angle on the fold. This angle is frequently connected along the fold with the outward angle of the median line; terminal line dark brown, rather indistinct. The lines are often obliterated more or less, especially the median. Fringes dark leaden gray. Hind wings dark fuscous; fringes a little lighter. [Fernald, 1896.] (See fig. 1.)

The moths vary somewhat in color and distinctness of markings, some specimens being much darker than others when first transformed. In the hind wing the frenulum is a single short spine in the male. In the female the frenulum is more slender and is very finely divided at the tip. In the female of a number of other species of this genus the frenulum consists of two distinct spines.

LIFE HISTORY.

HABITS OF THE MOTHS.

The moths fly during late afternoon, on dark days, and during the early part of the night. They are attracted to light, but in comparatively small numbers considering their great abundance at certain times. The majority of the females collected at trap lights are those which have deposited their eggs. During the day, when disturbed, they make short, erratic flights, usually alighting head downward on the stems of weeds and grasses, their tightly closed wings and grayish color making them very inconspicuous. As with other members of the genus *Crambus*, their long palpi, extending parallel to the stem of the plant on which they are at rest, help to make the outlines of the body conform to the appearance of that part of the plant.

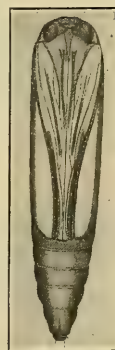


FIG. 5.—*Thetobacco*
Crambus: Pupa.
Much enlarged.
(Original.)

OVIPOSITION.

When the moths were confined in cages, the eggs were deposited at random over the surface of the ground. They seemed dry when deposited, rolled about easily, and did not adhere to papers placed over the soil in the rearing cages, or to glass when females were confined in large test tubes. Normally the eggs are doubtless placed in the same manner, for on two occasions eggs were found on the upper surface of leaves of sweetbrier lying flat on the ground. Egg laying commences shortly after the moths emerge. Fertile eggs were not obtained from moths reared in the cages.

Records obtained from a large number of females, collected in the fields and placed in separate cages for egg deposition, show the average number of eggs laid to be 177. Among the records obtained at Appomattox, Va., during 1910, are those in Table II.

TABLE II.—*Number of eggs laid by the tobacco Crambus, Appomattox, Va., 1910.*

No. of female.	Moth collected.	Period of oviposition.	Number eggs laid.	No. of female.	Moth collected.	Period of oviposition.	Number eggs laid.
	1910.	1910.			1910.	1910.	
1	July 8.	July 9-13.	218	10	Aug. 11.	Aug. 12-15.	83
2	do.	do.	68	11	do.	Aug. 12-16.	203
3	do.	July 9-14.	271	12	Aug. 14.	Aug. 15-20.	218
4	July 10.	July 11-14.	156	13	do.	Aug. 15-18.	194
5	July 12.	July 13-18.	211	14	Aug. 15.	Aug. 16-20.	222
6	July 17.	July 18-22.	316	15	do.	Aug. 16-19.	91
7	do.	July 18-23.	287	16	do.	Aug. 16-21.	238
8	July 25.	July 26-30.	77	17	do.	Aug. 16-18.	63
9	Aug. 11.	Aug. 12-16.	301				

Several individual females laid over 300 eggs, and over 300 were obtained in several instances by dissection. It is probable that the average number of eggs deposited normally is above rather than below the average obtained in the cages, as some of the moths may have laid eggs before capture, although records were not included from moths which deposited eggs within 12 hours after capture.¹

The period of oviposition lasts from 3 to 5 days, the females dying shortly after egg laying is finished. The records of two females collected in the field on August 10, 1910, are given in Table III.

TABLE III.—*Rate of oviposition of the tobacco Crambus, Appomattox, Va., 1910.*

Female No. 1.		Female No. 2.	
Date.	Number of eggs deposited.	Date.	Number of eggs deposited.
	1910.		1910.
Aug. 11.	7	Aug. 10.	93
Aug. 12.	89	Aug. 11.	87
Aug. 13.	70	Aug. 12.	23
Aug. 14.	36	Aug. 13.	5
Aug. 15.	19		
Total.	221	Total.	208

DURATION OF THE EGG STAGE.

The period of incubation was found to be from 5 to 9 days, the greater number of eggs hatching about the sixth day at ordinary summer temperatures.

¹ The dissection of 17 females of *Crambus caliginosellus* collected in the field during the third week in July, 1912, showed that 8 of the 17 collected contained more than 100 eggs. The number of eggs (mature or nearly mature) found in the 8 moths containing more than 100 eggs was as follows: 143, 322, 127, 290, 307, 124, 342, 208.



FIG. 1.—INJURY OF THE TOBACCO CRAMBUS, OR "WIREWORM," TO TOBACCO.



FIG. 2.—INJURY OF THE TOBACCO CRAMBUS, OR "WIREWORM," TO CORN.

WORK OF THE TOBACCO CRAMBUS.



FIG. 1.—POOR STAND OF TOBACCO RESULTING FROM PLANTING ON WEEDY LAND.

Note heavy growth of oxeye daisy in part of field not in tobacco.



FIG. 2.—WILD CARROT AND OTHER WEEDS IN FIELD OF RED CLOVER.

Injury from the "wireworm" occurs when land of this kind is planted in tobacco or corn.

RELATION OF WEEDY LAND TO INJURY BY TOBACCO CRAMBUS.

TABLE IV.—Duration of egg stage of the tobacco Crambus, Appomattox, Va., 1910.

Lot No.	Eggs laid—	Eggs hatching—	Incubation period.	Lot No.	Eggs laid—	Eggs hatching—	Incubation period.
	1910.	1910.	Days.		1910.	1910.	Days.
1	July 7.....	July 12.....	5	8	Aug. 12.....	Aug. 17-18.....	5-6
2	July 11.....	July 19-20.....	8-9	9	Aug. 13.....	do.....	4-5
3	July 12.....	July 19.....	7	10	Aug. 14.....	Aug. 19-20.....	5-6
4	July 13.....	July 19-20.....	6-7	11	Aug. 15.....	Aug. 20.....	5
5	July 25.....	July 31.....	6	12	Aug. 16.....	Aug. 21-22.....	5-6
6	July 26.....	Aug. 1-2.....	6-7	13	Aug. 17.....	Aug. 23-24.....	6-7
7	Aug. 11.....	Aug. 16-17.....	5-6				

HABITS OF THE LARVÆ.

NATURAL FOOD PLANTS.

Larvæ of the tobacco Crambus have been found feeding on the following wild plants:

Buckhorn plantain (<i>Plantago lanceolata</i>).	Wild carrot (<i>Daucus carota</i>).
Oxeye daisy (<i>Chrysanthemum leucanthemum</i>).	Sheep sorrel (<i>Rumex acetosella</i>).
Wild aster or "stickweed" (<i>Aster ericoides</i> and other species).	Senecio (<i>Senecio jacobæa</i>).
	White-top (<i>Erigeron annuus</i> and other species).

The first two plants named, the buckhorn plantain and the oxeye daisy (Pl. II, fig. a), were found to be the main food plants of the larvæ in the localities studied. The eradication or control of these weed pests, therefore, will result in comparative immunity from loss by this insect. Both species of plants have been found heavily infested in many localities in widely separated sections. During early spring the plantain seems to be the preferred food plant; later a heavy infestation occurs on both plantain and daisy.

On July 8, 1910, 23 out of 25 oxeye daisy plants examined in a weedy field were infested, there being a total of 69 larvæ about the roots. As many as 20 larvæ have been collected from one plant of the oxeye daisy.

In tobacco-growing sections of Tennessee and Kentucky white-top is a frequent food plant.

When meadows are plowed up and planted to tobacco there is frequently serious injury from the "wireworms." (See Pl. II.) Where such injury has occurred the weeds mentioned above have invariably been found abundant in the sod, which explains the presence of the "worms." Injury has not been observed where there had been previously a clean growth of grass or clover. Attempts to rear adults from larvæ confined in field cages containing only timothy and clover resulted in failure, although the larvæ lived for a considerable time without other food.

INJURY TO TOBACCO.

The tobacco is attacked soon after planting, and feeding by the larvæ continues until the first or second week of July. The larvæ usually commence operations just below the surface of the ground, although newly set plants are frequently attacked at the "bud" or whorl of terminal leaves. As feeding continues the larvæ, especially the smaller ones, frequently enter the stalk and tunnel upward, the burrows often extending to the base of the first leaves and some distance above the surface of the ground. (See Pl. I, fig. *a*.) When not feeding the "worms" are found about the base of the plant, usually in cylindrical, web-lined galleries, which extend from the plant, often for several inches, beneath the surface of the soil.

Injured plants may usually be detected by their stunted or wilted appearance, which is more noticeable during hot, dry weather. The stems are in some cases entirely cut off, although this form of injury is rather unusual.

Although plants often partially recover they do not obtain full growth, and it is evident that the presence of many dwarfed or stunted plants must result in very materially lessening the yield. The value of the crop is greatly decreased also, owing to the large proportion of late plants resulting from replanting. Early planted tobacco is usually better in quality than the late planted, it being finer and more elastic, curing better, and consequently bringing higher prices. The attacks of the larvæ often make it necessary to reset the crop several times, and a good stand of plants is not secured, if at all, until too late to make the crop as profitable as it should be.

INJURY TO CORN.

Owing to its wide distribution in the Eastern States the tobacco *Crambus* is a serious pest to the corn crop. Injury has been noted in many localities where little tobacco is grown, and it is probable that damage to corn amounts to even more than that to tobacco. As with tobacco, injury is most severe when corn is planted on land which has been in weedy pasture or meadow previously, or when planted on land which has not been under cultivation for a number of years and on which there has been a rank growth of weeds. On such land it is usually difficult to secure a satisfactory stand of corn, and the yield is greatly reduced. (See Pl. I, fig. *b*.) In central Virginia many fields under observation were replanted several times, and owing to the lateness of the season when a stand was secured the value of the crop was decreased fully one-third. Corn or tobacco planted on newly-cleared land seldom suffers injury from the *Crambus*. Since the species of weeds which are the natural food plants of the insect do not thrive in woodland, the larvæ are not present when the crop is planted.

The larvæ attack the young corn near the surface of the ground and burrow into the base of the stalks, the outer portion of the stalk being frequently girdled. If the stalks are small when attacked, they are either killed or so stunted or dwarfed that they never fully outgrow the injury, and produce little or no grain. Much of the corn is attacked just after the seed has sprouted. The larvæ frequently burrow into the folded leaves as the corn is coming through the ground. As the leaves unfold they show transverse rows of holes. When the stalks reach a height of a foot or more comparatively little damage is done. Several larvæ are frequently found about the roots of a single stalk, and as many as 22 have been collected from a single hill of corn. In wet weather injury is not apt to be so severe, as the plants are then more vigorous and the weeds, which furnish suitable food for the worms, more plentiful. As with tobacco, corn is attacked when the natural food supply of the "worms" is cut off.

GENERAL FEEDING HABITS.

The feeding habits of the "wireworm" on plants other than corn and tobacco are, in a general way, the same. There is a tendency to girdle soft-rooted plants, such as plantain and the wild carrot (Pl. II, fig. b), and the larvæ are often found embedded in cavities where they have fed. The buckhorn plantain (*Plantago lanceolata*) is frequently killed where the infestation is heavy. A marked preference is shown for the natural food plants, and farmers, when the larvæ are especially troublesome, frequently take advantage of this fact by cultivating at first only one round to the row, allowing the weeds to grow in the center of the row until the corn or tobacco has become better established. In a plowed field the larvæ, if they have not finished feeding, concentrate about plantain, daisy, and stickweed (*Aster* spp.) which have not been killed by plowing.

The larvæ do not seem to travel far in search of food, as was ascertained by plowing badly infested land adjoining fields of corn and tobacco. When disturbed they crawl actively in either direction, and they will often spin a slender silken thread by which they may be suspended. They feed most actively at night.

THE PUPÆ.

The larvæ pupate in the soil near the plants on which they feed. Before pupation there often seems to be a rather long period during which the larvæ remain inactive in their cells. The pupal cells are usually found at a distance of from 1 inch to 6 inches from the base of the food plant and at a depth varying from one-half inch to 4 inches.

Table V shows the depths at which pupæ were found about various food plants in soils varying from hard stiff clays to loose sandy loams.

TABLE V.—*Depth at which pupation of the tobacco Crambus takes place, Appomattox, Va., 1910.*

Date.	Character of soil.	Food plant.	Depth.	Date.	Character of soil.	Food plant.	Depth.
1910.			<i>Inches.</i>	1910.			<i>Inches.</i>
July 9	Red clay.....	Tobacco....	2.5	July 11	Red clay.....	Tobacco....	1
Do.	Sandy loam.....	do.....	3.5	Do.	do.....	Corn.....	2.5
Do.	do.....	Plantain....	1	Do.	Sandy loam.....	Daisy.....	.5
Do.	Red clay.....	do.....	.5	Do.	Red clay.....	Plantain....	1
Do.	Black loam.....	Daisy.....	4	Do.	do.....	Daisy.....	1.5
July 11	Gray sandy loam..	Tobacco....	3.5				

Numerous measurements made at different times gave results very similar to those shown above. The average depth at which pupation takes place was found to be about 1.5 inches.

The cells averaged about 9.5 mm. in length and 4.5 mm. in width (inside measurements). The lower portion of the cell is usually somewhat larger than the upper portion, the pupa lying in the larger end of the cell in convenient position for its egress. The cells are extremely fragile and are easily broken when removed from the soil. They are constructed of fine particles of earth and grains of sand interwoven with a silky weblike material. The walls are thin and the interior surface quite smooth.

The pupal period, as shown in Table VI, lasts from 10 to 15 days.

TABLE VI.—*Pupal period of the tobacco Crambus, Appomattox, Va., 1911.*

Larvæ collected—	Pupated—	Moth emerged—	Number of days.	Larvæ collected—	Pupated—	Moth emerged—	Number of days.
1911.	1911.	1911.		1911.	1911.	1911.	
June 18.....	July 7-10....	July 21.....	11-14	July 1.....	July 8.....	July 22.....	14
Do.....	July 10-11....	do.....	10-11	July 12.....	Aug. 1-3....	Aug. 15.....	12-15
June 20.....	July 7-9.....	July 22.....	15-17	Do.....	July 15.....	Aug. 1.....	15
Do.....	July 12.....	do.....	10	Do.....	July 28-31..	Aug. 10.....	10-13
Do.....	July 15.....	July 26.....	11	Do.....	Aug. 1-2....	Aug. 15.....	13-15
July 1.....	July 28-31..	Aug. 10.....	10-13	Do.....	Aug. 1.....	Aug. 12.....	12

Table VII shows the duration of the period during which the insect is in the pupal cell before and after pupation.

TABLE VII.—*Duration of prepupal and pupal periods of the tobacco Crambus at Appomattox, Va., 1911.*

Number of record.	Larvæ ceased feeding—	Moth emerged—	Days.	Number of record.	Larvæ ceased feeding—	Moth emerged—	Days.
	1911.	1911.			1911.	1911.	
1	June 18.....	July 10.....	22	7	July 9.....	Aug. 1.....	23
2	do.....	July 15.....	27	8	July 11.....	July 24.....	13
3	do.....	July 16.....	28	9	July 13.....	July 29.....	16
4	July 3.....	July 18.....	15	10	July 14.....	Aug. 3.....	20
5	do.....	July 20.....	17	11	do.....	July 29.....	15
6	do.....	July 19.....	16				

NATURAL ENEMIES.

In spite of its long larval period the tobacco Crambus does not seem to be largely parasitized, at least during the later stages, this being due presumably to the subterranean habits of the larvæ and the protection afforded by the loose web in which they usually lie when not feeding. Nevertheless parasitic and predaceous enemies are doubtless factors in keeping the insect in check. The vast number of newly hatched larvæ as contrasted with the number found later in the season shows that comparatively few survive the earlier larval stages. This reduction is due in part to various natural enemies the exact or relative importance of which it is hard to estimate.

Various carabid beetles have been observed to feed on the larvæ. Among them were *Calosoma calidum* Fab. and *Chlænium tomentosus* Say. Adults and larvæ of Harpalus (*Harpalus pennsylvanicus* De G. and *H. faunus* Say) were observed to be very abundant about roots of oxeye daisy and plantain which were heavily infested with Crambus larvæ. As the species of Harpalus are known to be general feeders, they were thought to feed on the larvæ of the Crambus. The adults, when confined in tubes with larvæ, occasionally fed on them.

Spiders of several species were observed to feed on the larvæ, and large numbers of the moths are captured in spider webs in weedy fields.

Ants also occasionally attack the larvæ. An ant found carrying a partly grown larva at Chatham, Va., was examined by Mr. Theodore Pergande and found to be a species of Solenopsis.

W. G. Johnson, in Maryland, reported the rearing of an undetermined hymenopterous parasite from the larvæ. No parasitic Hymenoptera were secured from the rearing cages at Appomattox, although large numbers of larvæ were confined.

Several Diptera were observed in cages containing larvæ on various occasions, but actual proof of parasitism was not obtained, although a species of Phoridae was secured from tubes containing larvæ under circumstances pointing strongly to parasitism.

In the National Museum are specimens of a hymenopterous parasite, *Perisemus prolongatus* Prov., labeled as reared from larvæ of *Crambus caliginosellus* from La Fayette, Ind. The record is doubtful, however, as the notes concerning the specimens in the files of the Bureau of Entomology clearly refer to a different species of Crambus as the host.

Birds are a factor in keeping the tobacco Crambus in check. Two species, the quail (*Colinus virginianus*) and the kingbird (*Tyrannus tyrannus*) were observed by the writer to capture the moths, and others are known to feed freely on moths of this genus. F. M. Webster states that the wood pewee (*Myiochanes virens*) was observed to

destroy large numbers of *Crambus laqueatellus* at Haw Patch, Ind., and C. H. Fernald observed barn swallows feeding on different species of *Crambus* in Maine. Meadowlarks frequent weedy fields which harbor the larvæ of *Crambus*, and as these birds are known to feed on various species of cutworms, they doubtless feed also on the larvæ of the tobacco *Crambus*.

REPRESSION.

CULTURAL METHODS OF CONTROL.

Injury from the tobacco *Crambus* occurs where crops susceptible to injury are grown on weedy land. Tobacco or corn planted on land which has been under clean cultivation the previous year and kept free from weeds which live throughout the winter does not suffer serious injury. *The larvæ can not live over winter in the soil from the previous summer unless plants on which they are able to feed are present.* All field experiments and observations so far have shown that the most effective means of control consist of freeing the land from the weeds, such as buckhorn plantain, daisy, stickweed, etc., which have been found to be the natural food plants of the larvæ.

There are many methods by which weeds may be eradicated or controlled, but the most practical and effective is the systematic rotation of crops. Sowing clean seed, preventing weeds from ripening seed, fall or winter plowing, the use of lime or of certain fertilizers, and doing away with wide fence rows are important preventive measures. Mowing and burning over weedy fields destroys many weed seeds and weeds which live over winter, and also destroys many injurious insects. Burning during August or September has been found to destroy the eggs and young larvæ of the tobacco *Crambus*, but as this method destroys humus, which is so badly needed in most tobacco soils, it is in most instances not advisable.

Many weeds are "soil indicators," their presence showing that the soil is lacking in fertility and in some instances pointing to a deficiency of lime.

CLEAN SEED.

One of the main factors in the control of weeds is clean seed, and the importance of procuring such seed can hardly be overestimated. Many weed pests are introduced and disseminated in the seed of various crops, such as grass and clover. As tobacco or corn must frequently be grown on land which has previously been in these crops, and as injury from the tobacco *Crambus* is apt to occur if the meadows have been weedy, it is desirable, for this and other reasons, to have the meadows as free from weeds as possible.¹ Owing to

¹ An analysis made by the Massachusetts Experiment Station shows that 1 ton of oxeye daisy (cured) withdraws from the soil approximately 25 pounds of potash, 8.7 pounds of phosphoric acid, 22 pounds of nitrogen, and 26 pounds of lime. To restore the stated amounts of the first three constituents to the soil it would be necessary to apply about 50 pounds of muriate of potash, 65 pounds of superphosphate, and 140 pounds of nitrate of soda. (Farmers' Bul. 103, U. S. Dept. Agr.)

careful cultivation of previous crops, the land is frequently fairly free from weeds when seeded to meadow; so that if the clover and grass seed has been sown pure there will be few weeds in the tobacco field or cornfield.

An examination of samples of clover and grass seed procured from farmers and seedsmen in various sections of Virginia shows that seeds of buckhorn plantain and oxeye daisy—both natural food plants of the tobacco Crambus—are common. Of 30 samples examined by the seed expert of the Virginia State department of agriculture during 1910, 28 contained seeds of oxeye daisy, and of these, 5 contained plantain and daisy. Of 70 samples of clover, redtop, and timothy seed examined at the Virginia Experiment Station in 1909, seeds of buckhorn plantain were found in 16.¹

The United States Department of Agriculture and those in charge of similar work in many of the States have provided means by which samples of seed may be examined for purity by experts. Some of the States, also, have laws compelling dealers to furnish a stated guaranty as to the purity of the seeds sold.

WEEDS TO BE ELIMINATED.

The buckhorn plantain (*Plantago lanceolata*) is one of the numerous naturalized weed pests from Europe. It ranks among the worst weeds, particularly upon the lighter soils and on clay uplands. "Ray-bud," "rib-grass," "ribwort," "buck plantain," "English plantain," "ripple," "ripple grass," and "narrow plantain" are names applied to the plant in different sections. It is perennial or biennial and is common in meadows. The seeds are widely distributed with clover seed, from which it is difficult to separate them. Rotation of crops, thorough cultivation, and the use of clean farm seed are the usual methods for its control.

The oxeye daisy (*Chrysanthemum leucanthemum*) (Pl. II, fig. a) is also a naturalized species from Europe. It is often abundant on old or poor soil. It spreads from the seeds, which are distributed in various farm seeds, in hay, and in manure; also, by shoots from the perennial root stocks, which must be entirely killed before the plant can be wholly eradicated. It is best controlled by rotation of crops, by smothering out by means of cowpeas or other suitable soiling crops, and by thorough cultivation. It is a bad weed pest in meadowland. The seed can be prevented from ripening by mowing the hay early.

White top or fleabane (*Erigeron annuus* and other species) is a common pest in meadows. In some localities it has been found to be a food plant of the tobacco Crambus. Early mowing of infested meadows before the seeds ripen and pasturing with sheep, which

¹ Bul. 184, Va. Agr. Exp. Sta.

readily eat the weed, are control methods commonly practiced. Chemical sprays are fairly effective, but can not be used in meadows where clover is grown, as clovers are killed by the solution. Sprays have been found most effective while the plant is in bloom.

The stickweed or aster (*Aster ericoides*), known also as frostweed, steelweed, white heath, etc., and related species, are common and abundant weeds in old fields in tobacco-growing sections of the Atlantic States. They are perennial and thrive on poor soil. It is useless to try to eradicate them completely, but they can be readily controlled by growing cultivated crops and by putting the land in a higher state of fertility by the use of lime and clover. Aster is not a usual food plant of the tobacco Crambus, but as the weed is so frequently associated with daisy and plantain, which thrive best under similar soil conditions, its control is essential in the preparation of land for tobacco.

CROP ROTATION.

One of the main reasons for a rotation of crops is that the accumulation of weeds in meadowland and pastures may be destroyed during the cultivation of the crop that follows. A rotation found very satisfactory by the Virginia experiment station has been devised by Mr. E. H. Mathewson, Crop Technologist of the Bureau of Plant Industry. This plan is slightly modified to meet conditions in different tobacco-growing sections. It calls for a seven-year rotation of crops, as follows: *First year*, tobacco, fertilized heavily; *second year*, wheat without fertilizing; *third and fourth years*, mixed grasses and clover, seeded alone early in the fall and top dressed early in the spring with 200 to 300 pounds of nitrate of soda; *fifth year*, corn, with barnyard manure and a small amount of fertilizer; *sixth year*, cowpeas, fertilized with a little acid phosphate and sulphate of potash; *seventh year*, tobacco.

Crops such as cowpeas, soy beans, and crimson clover, which aid so greatly in fitting land for increased and more profitable yields of tobacco and corn, not only add humus to the soil and increase the fertility, but help to eradicate certain weeds by smothering them out. The weeds are also destroyed or prevented from maturing seed when crops are plowed under. Although eggs of the Crambus may have been deposited in such a field, the larvæ can not survive until the tobacco is planted unless there are weeds which remain alive over winter to supply them with food.

The following rotation experiments have been under observation during the present investigation:

A test with tobacco following crimson clover was conducted as a cooperative experiment on the J. R. Horsley farm in Appomattox County, Va., in the season of 1910-11. The field selected contained

4 acres. It was in corn during the season of 1910. Previous to plowing for corn the field was in weedy sod. The corn was badly injured by the *Crambus* and was replanted twice. At the last cultivation of corn in July, crimson clover was sown. Rains were frequent during the latter part of the summer, and a fairly good stand of clover was secured. There were some weeds, in spots, which cultivation at the time clover was sown had not destroyed. The field was planted to tobacco during the season of 1911. Damage by the *Crambus* was estimated to be about 6 per cent.

A test with tobacco following cowpeas was conducted as a cooperative experiment on the S. L. Ferguson farm, Appomattox County, Va., in the seasons of 1911 and 1912. A field containing about 6 acres was used in the experiment. The land previous to plowing for cowpeas was in weedy pasture, and numerous *Crambus* larvæ had been observed. A good growth of the cowpeas was secured. The land was deeply plowed during winter and was prepared for planting to tobacco during the third week in May, 1912. Scarcely any injury from the *Crambus* to the first planting was observed. After the first planting damage from the *Crambus* and from other causes was estimated to be less than 4 per cent. In the check field, where conditions were similar to those in the experimental field, except that a crop of cowpeas had not been grown, there was an estimated damage from the *Crambus* of about 9 per cent. The sod in the check had been winter-plowed.

In the plats of the Virginia Tobacco Experiment Station, at Appomattox, nine experiments were under observation, as detailed below.

The first experiment was with tobacco planted on sod in an old weedy pasture. A large part of the first planting was destroyed. The plat was replanted three times. About 9 per cent of a stand was secured by the second week in July. Owing to injury from "wireworms" and the large percentage of late plants the value of the crop was decreased 25 per cent as compared with plats in which an early stand of plants had been secured.

The second experiment was with tobacco following cowpeas on land that had been uncultivated for several years and was very weedy. Almost a perfect stand of plants was secured at the first planting, which was made the last week in May. The injury (decrease in the value of the crop) was less than 1 per cent.

The third experiment was on a plat used for fertilizer tests. The condition of the land was similar to that used in the second plat, except that cowpeas had not been grown during the preceding season. The tobacco was replanted three times. The decrease in the value of the crop was 7 per cent.

The fourth experiment was again with tobacco planted on sod. There were few weeds in the sod. Nearly a perfect stand of plants was secured at the first planting, which was made during the last week in May. The plat was replanted once. The loss was estimated at less than 1 per cent.

The fifth experiment was again with tobacco following cowpeas. A perfect stand of plants was secured at the first planting, made during the last week in May. Injury from the tobacco Crambus was estimated at less than 1 per cent.

The sixth experiment was with tobacco planted on red-clover sod. The stand of clover had been good and there were few weeds. Tobacco was planted during the last week in May. A good stand was secured at the first planting. Loss from the Crambus was estimated at less than 1 per cent.

The seventh experiment was on spring-plowed land where stickweed, daisy, and plantain had been abundant. The tobacco was planted during the second and third weeks in May. The loss was estimated to be about 20 per cent, owing to late plants, the tobacco having been replanted three times. Injury from the Crambus was worst in the portion of the field where weeds had been most abundant.

The eighth experiment was with tobacco following rye. The stand of rye had been poor and the stubble was weedy. The first planting was made on June 8, and was almost completely destroyed. Tobacco was replanted three times. A stand of 90 per cent was secured by the second week in July. The estimated decrease in the value of the crop was about 30 per cent.

The ninth experiment was with tobacco following cowpeas. The first planting was made on June 2. About 20 per cent of plants were injured by "wireworms." The plat was replanted once, there being only slight damage after the second planting. The estimated loss in value of the crop was about 10 per cent. Most of the injured plants were in the end of the plat where the stand of peas had been poor.

Three experiments were under observation at the Virginia Tobacco Experiment Station at Chatham in 1910 by Mr. R. P. Cocke, superintendent of the station.

In experiment No. 1 tobacco was preceded by corn in which crimson clover was sown at the last cultivation. This clover was fallowed May 2. The corn was kept clean of weeds and grass. Tobacco was set June 6. The first replanting was made June 14 with 5 per cent of the plants injured; the second replanting was made June 23, with 3 per cent injury; and the third replanting, June 28, with 2 per cent injury. About 97 per cent of a stand was finally secured after the third replanting.

In experiment No. 2 tobacco followed corn, in a plat used for fertilizer tests. Tobacco was set June 6. The first replanting was made June 14, with 5 per cent injury; the second replanting, June 23, with 3 per cent injury; and the third replanting, June 28, with 2 per cent injury. About 98 per cent of a stand was secured after the third replanting.

In experiment No. 3 tobacco was planted after a cover crop of wheat, in variety test plats. The wheat was fallowed May 1. Tobacco was set June 7. The first replanting was made June 17, with 20 per cent injury, and the second replanting, June 28, with 6 per cent injury. About 95 per cent of a stand was secured. In these plats it was estimated that about 5 per cent of the entire loss was due to cutworms and to true wireworms (larvæ of Elateridæ).

SUMMER PLOWING.

The moths are local in habits and do not fly far from the weedy fields, which furnish protection for them and which are suitable places for them in which to deposit eggs. On emerging from plowed or bare land, or from fields in which the vegetation is not suitable for protection or for egg deposition, they fly to surrounding fields where conditions are more favorable. The land from which emergence took place will then be left free from worms which, if present would attack the crop the following year.

The preparation of weedy land for tobacco or corn must, therefore, be commenced the season before the crop is planted. Best results have been obtained by summer plowing, as the land was thus rendered bare of vegetation, and conditions were not suitable for egg laying when the moths emerged. By this means infestation of the land is prevented in the first place. It has been found that it is difficult to prevent injury, or to eradicate the worms, if they have once become established. Summer treatment of land makes conditions unfavorable for the moths to deposit eggs, destroys weeds which furnish food for the young larvæ, and kills many of the insects while in the pupal stage.

The results of an experiment made in 1910 to ascertain the effect of plowing on pupæ is given in Table VIII. Larvæ were placed in large field cages. When the greater number had pupated, one of the cages was removed temporarily and the land plowed.

TABLE VIII.—*Effect of plowing on pupal stage of the tobacco Crambus.*

Cage No.	Number of larvæ.	Collected.	Moths emerged.	Number.	Per cent.
1.....	200	June: Second and third week...	July: Third and fourth week..	84	42
2 (check)...	200	do.....	do.....	118	59

Pupation takes place at an average depth of $1\frac{1}{2}$ inches. The pupal cells are fragile and easily broken up by plowing or disking. Many of the pupæ are deeply buried by plowing and the moths are unable to reach the surface.

The satisfactory results following summer treatment of land, whether or not cowpeas or other similar crops are grown, are mainly due to the fact that conditions are made unfavorable for the deposition of eggs by the moths and for the growth of newly hatched larvæ.

FALL AND WINTER TREATMENT OF LAND.

During September, 1909, two cultural experiments were begun in Appomattox, Va., to ascertain the effect of fall and winter treatment of land already infested with *Crambus* larvæ.

The field selected on the J. F. Purdum farm contained five plats of one-half acre each. In this experiment (experiment A) fall and winter preparation of the tobacco land gave decidedly beneficial results. The field had been in pasture previous to plowing, but the growth of weeds was not so rank as on the land used in experiment B. The following were the results obtained in each of the plats:

Plat No. 1.—Ground plowed during second week in December, 1909. Thoroughly disked during first week in January, 1910. Tobacco planted during last week in May. Number of plants, 2,200. Number replanted, 89. Per cent injured, 4+.

Plat No. 2.—Land plowed during first week in January, 1910. Disked during second week in February. Tobacco planted during last week in May. Number of plants, 2,350. Number of plants reset, 165. Per cent injured, 7+.

Plat No. 3.—Land plowed during last week in February, 1910. Disked during third week in March. Tobacco planted during last week in May. Number of plants, 2,280. Number of plants reset, 138. Per cent injured, 6+.

Plat No. 4.—Land plowed during third week in March, 1910. Disked during third week in April. Tobacco planted during last week in May. Number of plants, 2,214. Number of plants reset, 251. Per cent injured, 11+.

Plat No. 5 (check plat).—Land plowed during third week in April. Prepared for planting during last week in May. Tobacco planted during last week in May. Number of plants, 2,225. Number reset, 375. Per cent injured, 17+.

Tobacco in all plats was replanted twice. A good stand of plants (about 98 per cent) was secured by July 4. After July 4 there was but slight injury from the worms. The land had been heavily fertilized, and the tobacco made a fine growth.

The second tobacco cultural experiment was conducted on the farm of Mr. J. R. Horsley (experiment B), in Appomattox County, Va. Four plats, each containing 1 acre, were included in the experiment. Two check plats, one at each end of the experimental plats, were used. Each of these contained 1 acre. The growth of weeds was heavy, stickweed, daisy, and buckhorn plantain being abundant.

In this test beneficial results from fall and winter plowing were not so conclusive as in the experiment on the Purdum farm (experiment

A). On plat No. 1 the effect of mowing and burning the weeds after the eggs had hatched was noted.

Plat No. 1.—Weeds mowed and burned during third week in September, 1909. The land was not disturbed until the ground was prepared for planting, during the third week in May. Number of plants in plat, 4,400. Number of plants reset, 610. Per cent injured, 13.8+. Tobacco replanted twice.

Plat No. 2.—Ground plowed during last week in September, 1909. In March, April, and May it was disked and harrowed at frequent intervals, no vegetation being allowed to grow before the tobacco was planted, in order, if possible, to starve out the hibernating larvæ. Number of plants, 4,400. Number replanted, 415. Per cent injured, 9.4+.

Plat No. 3.—Land plowed during second week in March and not disturbed until just before planting. Number of plants, 4,400. Number of plants reset, 410. Per cent injured, 9.3+.

Plat No. 4.—Land plowed during third week in December, 1909. Nothing further done to it until prepared for planting during last week in May, 1910. Number of plants, 4,400. Number replanted, 540. Per cent injured, 12.2+.

The results of these experiments are shown also in Table IX.

All plats were replanted twice. A good stand of 98 per cent was secured by July 5.

TABLE IX.—*Effects of fall and winter treatment on injury by the tobacco Crambus in 1909 and 1910.*

Experiment No.	Preliminary treatment.	Time of treatment.	Later treatment.	Time.
A1	Plowed.....	Second week of December, 1909.....	Thoroughly disked.	First week of January, 1910.
A2	do.....	First week of January, 1910.....	Disked.....	Second week of February.
A3	do.....	Last week of February.....	do.....	Third week of March.
A4	do.....	Third week of March.....	do.....	Third week of April.
A5	do.....	Third week of April.....		
B1	Weeds mowed and burned.	Third week of September, 1909.....	Disked and harrowed at frequent intervals.	March, April, May.
B2	Plowed.....	Last week of September.....		
B3	do.....	Second week of March.....		
B4	do.....	Third week of December.....		
B5	do.....	First week of April.....	Disked.....	First week of May.

Experiment No.	Planted tobacco.	Number of plants.	Number reset.	Per cent injury.
A1	Last week of May.....	2,200	89	4
A2	do.....	2,350	165	7
A3	do.....	2,280	138	6
A4	do.....	2,214	251	11
A5	do.....	2,225	375	17
B1	Third week of May.....	4,400	610	13.8
B2	do.....	4,400	415	9.4
B3	do.....	4,400	410	9.3
B4	do.....	4,400	540	12.2
B5	do.....	8,800	1,218	13.9

In the season of 1910-11 another series of cultural experiments was conducted on the J. F. Purdum farm, in Appomattox County, Va. The land previous to preparation for tobacco was in meadow

(timothy, herd's grass, and clover) which had been quite weedy. Natural food plants of the tobacco Crambus were abundant. This series was made for the purpose of ascertaining the effect on the tobacco Crambus of preparation of weedy land at different times during the fall and winter as compared with spring preparation of land. The field was divided into 6 plats containing one-half acre each. Tobacco was planted in all plats on the same date. The amount of fertilizer applied to each plat was the same.

In plat No. 1 the land was plowed September 6, 1910, and fallowed February 25, 1911. It was harrowed and disked on April 3, April 10, April 20, and May 3. The stand of tobacco was nearly perfect after the first planting except along one end of the plat. The percentage of a stand secured was 95.4. In the preparation of this plat it will be noticed that the land was plowed during the first part of September, a time just after the larvæ had hatched.

Plat No. 2 was plowed December 8, 1910, and fallowed February 28, 1911. It was harrowed and disked on April 3, April 10, April 20, and May 3. Tobacco was replanted once. About 85 per cent of a stand was secured at the first planting.

Plat No. 3 was plowed January 8, 1911, and fallowed or replowed February 28, 1911. It was harrowed and disked on April 3, 10, and 20 and May 3. Tobacco was replanted once. About 85 per cent of a stand was secured at the first planting.

In plat No. 4 the land was plowed on April 11. No further treatment was given until the third week in May, when the land was prepared and bedded for planting. The tobacco was replanted three times. About 51 per cent of a stand was secured at the first planting.

In plat No. 5 the land was plowed on January 18, 1911, and disked May 15. Tobacco was replanted three times. About 70 per cent of a stand was secured at the first planting.

Plat No. 6 served as a check plat. The land was plowed during the third week in April, and was prepared for planting on May 15. Tobacco was replanted three times. About 55 per cent of a stand was secured after the first planting.

Further cultural experiments were conducted on the S. L. Ferguson farm, in Appomattox County, Va., in the season of 1911-12. This series was made to ascertain the effect of deep winter plowing and subsoiling of pasture land infested by the Crambus. The field of which the experimental plats were a part had been in sod for a number of years and was used as pasture land. The general conditions for the experiment were ideal. The oxeye daisy, buckhorn plantain, and stickweed were abundant. There was not a rank growth of weeds, however, as the field had been quite closely pastured. The field was deeply plowed in February, a subsoil plow following the turning plow, and the clay subsoil was broken up to a depth of several

inches. The tobacco in all plats was planted at the same time. The kind and amount of fertilizer applied was the same in all plats, and after the first cultivation all plats received the same treatment. The land was divided into 3 plats of 2 acres each and 1 plat containing one-half acre. Below are given the details of each experiment and the results obtained.

Plat No. 1 contained 2 acres. It was deeply plowed and subsoiled in February, 1911. The land was thoroughly disked and harrowed at frequent intervals during March, April, and May and kept almost entirely free from weed growth until tobacco was planted. The stand of tobacco was practically perfect. Only an occasional plat could be found which showed damage from *Crambus* larvæ.

Plat No. 2 contained 2 acres. The land was deeply plowed and subsoiled in February, 1911, and was not disturbed until prepared for planting in May, when it was deeply disked, harrowed, and bedded just before planting. Ninety-four per cent of a stand was secured at the first planting. The plat was reset once.

Plat No. 3 contained one-half acre. The land was plowed and subsoiled in February, 1911, as in plats Nos. 1 and 2. The land was not disturbed until prepared for planting as in plat No. 2. Weeds and grass were allowed to grow after planting. The middle of the row was not disturbed until after the first cultivation, in order to provide natural food for the *Crambus* larvæ, so that they would not be forced to attack the tobacco plants. The infestation of this plat was not heavy enough, so that the effect of this treatment, which is said to be practicable under certain conditions, could be accurately determined. The stand of tobacco secured at the first planting was 96 per cent. A few larvæ were found in the weeds left in the middle of the row.

Plat No. 4 was used as a check. The land was plowed and prepared for planting just before the tobacco was set out. The weed growth and general conditions were similar to those in plats Nos. 1, 2, and 3. The stand secured at first planting was 86 per cent. The tobacco was replanted twice. In land adjoining this tract which had been under clean cultivation during the previous summer and where there was no weed growth, about 98 per cent of a stand of tobacco was secured at the first planting. This land had been prepared for planting in practically the same manner as in the check plat, No. 4.

CHEMICAL SPRAYS FOR WEED DESTRUCTION.

Certain chemical sprays, such as iron-sulphate (copperas) solution, copper-sulphate (bluestone) solution, and common-salt solution, are frequently used for eradicating weeds and under certain conditions have been found very effective. The success of this method of eradicating such weeds as oxeye daisy and wild mustard from grain and pasture fields without injury to the grains or grasses depends largely

on the fact that cereals and grasses are narrow-leaved plants with a single seed leaf, whereas the weeds injured are broad-leaved plants with two seed leaves. Spraying with a solution of iron sulphate at a strength of 1 pound to one-half gallon of water was found to be fairly effective on the oxeye daisy in a test made at Appomattox, Va. While spraying may be practical where certain weeds in grain fields are to be eradicated, it is hardly a suitable remedy under most conditions in tobacco-growing sections, except possibly where small patches of weeds are to be destroyed. Chemical sprays have been found to be more effective when applied on warm bright days when the plants are dry. Immediately after weeds have been cut off close to the ground an application of salt, kerosene, crude oil, or acid solutions will often be found effective. In eradicating weeds from pastures the salt solution is preferable, as copper-sulphate solution is poisonous to stock.

LIMING.

Aside from improving the mechanical and chemical condition of many soils, liming will be found to aid greatly in the control of several of the weed pests which have been found to be the natural or favorite food plants of the tobacco Crambus. Control of weed pests may be accomplished by making soil conditions less favorable for the weeds, or by making conditions more favorable to the cultivated crop. Many weed pests, like other plants, require for their best development certain soil conditions; and they are excessively abundant in certain localities because soil conditions are peculiarly favorable to their growth, or because conditions are less suited to more desirable plants which under favorable soil conditions would crowd them out. A change in the condition of the soil, brought about by the use of lime, will often bring about a marked effect in checking or preventing the growth of a weed pest, and at the same time make the soil better adapted to the growth of certain cultivated crops such as clover.

The sheep sorrel¹ (*Rumex acetosella*), on which newly hatched Crambus larvæ frequently feed, thrives in acid soil. Where lime had been applied to certain fields, and to some of the State experiment station plats in Appomattox County, Va., the sheep sorrel was practically eradicated or at least checked by the better growth of the clover. Plantain, daisy, and aster (stickweed), all food plants of the worms, are weeds which flourish in acid or worn-out soils. In all cases where data have been secured, the use of lime has resulted in a marked decrease in the abundance of these weeds. Most soils in the Piedmont region of the Eastern States are greatly benefited by lime, and its use has in many instances resulted in markedly increased yields of tobacco. In plats of alfalfa at the Appomattox experiment station

¹ Attempts to rear larvæ in cages containing only sheep sorrel were not successful.

there was scarcely any plantain (*Plantago lanceolata*) after a heavy application of lime had been made, and there was an excellent crop of alfalfa. In the unlimed check plats plantain nearly covered the ground, and there was a very poor growth of alfalfa.

Increased fertility of the soil may also aid in the extermination of a weed, as was noticed where heavy applications of acid phosphate had been made to meadow land on which there was a heavy growth of the oxeye daisy. The year following the application of the acid phosphate but few plants of the daisy could be seen. In this manner certain weeds may often be crowded out by grasses or clovers which are enabled to make better growth owing to greater fertility.

The experience of the best tobacco growers has shown that intensive culture gives largest profits, and no expense or trouble should be spared in putting the ground in the best possible condition in every respect before the crop is planted. By commencing the preparation of weedy land the year before it comes in corn or tobacco, an excellent opportunity is afforded to apply lime. Such land can often be conveniently plowed in winter and during spring or early summer, and easily be put in condition for such crops as crimson clover, cowpeas, etc., which may be profitably followed by tobacco or corn the succeeding year.

FERTILIZERS.

From observations of tobacco fields during the seasons of 1910 and 1911 it is evident that where the land receives heavy applications of nitrogenous fertilizers the damage from the worms is not so great as where light applications are made. Just as many plants are attacked by the worms, but vigorous and rapidly growing plants are more apt to recover from injury. This was very noticeable in the fertilizer test plats of the Virginia experiment station at Appomattox in 1910.

INSECTICIDES AND REPELLENTS.

The following insecticides and repellents were tested: Arsenate of lead, Paris green, tobacco extract, nicotine sulphate, tobacco dust, kerosene, kainit, and calcium cyanamid. In no instance were results secured which would indicate that the substances tested were of much practical value in combating the tobacco Crambus. The following field notes give details of some of the experiments:

ARSENATE OF LEAD.

In experiment A, with powdered arsenate of lead, $1\frac{1}{2}$ ounces of the poison to $2\frac{1}{2}$ gallons of water was used. Two hundred plants were treated, the entire plant being dipped into the solution. The plants were set in land which had been prepared a few days before. The field had been weedy and the worms were numerous. Two hundred untreated plants were kept as a check. On examining the plants five days later 22 injured plants were found in the poisoned plat and 36 injured plants in the

check plat. Three live larvæ which had tunnelled in the stalks and were apparently uninjured were found in plants in the poisoned plat. All treated plants had lived, but were not as vigorous in appearance as those not treated.

In experiment B, with arsenate of lead paste, the poison was used at the rate of 2 ounces to $2\frac{1}{2}$ gallons of water. The tops only were dipped. One hundred plants were treated and 100 left untreated. The plants were examined five days after transplanting. There had apparently been some injury from the poison, as the plants were in best condition in the untreated plat, while those treated were somewhat stunted or dwarfed. Eight injured plants were found in the poisoned plat. Five plants were found injured in the untreated plat.

PARIS GREEN.

Paris green at the rate of one-fourth ounce to 3 gallons of water was used on 100 tobacco plants, and an adjoining row kept as a check. The entire plant was dipped in each case, and the plants set out at once. The field was weedy. It had been recently plowed and *Crambus* larvæ were numerous. A light rain fell a few hours after the plants were set. After eight days the plants were examined. Twenty-one plants were injured by worms in the poisoned row and 26 in the unpoisoned row. There had been some injury to the plants dipped in the poison solution, as the unpoisoned plants had a more vigorous start. In some instances plants in the poisoned row were only slightly eaten, thus indicating that the poison had acted as a repellent or had poisoned the worm before the plant had been badly eaten.

TOBACCO EXTRACT.

One row of tobacco plants in a field was sprayed with a 500-to-1 solution of tobacco extract, 320 plants in all being treated. The solution was applied with a compressed-air bucket sprayer. The substance did not prove effective in preventing injury. On June 6, five days after the mixture was applied, the plants were examined. Fourteen plants were found injured by worms in the sprayed row and 11 injured plants were found in the unsprayed row adjoining.

NICOTINE SULPHATE.

A 1,000-to-1 solution of nicotine sulphate was sprayed on 300 plants as in the foregoing experiment, and an adjoining row used as a check. The plants were examined four days after spraying. Eight plants had been attacked by worms in the sprayed row and 13 plants in the check row. While the foregoing substances did not prove of much value in preventing injury from the worms, they seemed to repel flea-beetles, as very few could be found on the treated plants whereas they were comparatively abundant on the unsprayed plants.

TOBACCO DUST.

Tobacco dust was scattered about tobacco plants directly after planting. One row containing 300 plants was used for the test and an adjoining row with the same number as a check. Eighteen plants were found injured by worms in the treated row. Few plants were found that were injured below the surface of the ground, the worm having entered the plant at the "bud" or terminal leaf in most cases. Sixteen injured plants were found in the row where the dust had not been applied. More of these plants had been injured below the surface of the soil than where dust had been applied, this indicating that the dust may possibly have some value as a repellent.

KEROSENE.

In the first experiment with kerosene the plants were dipped in a weak solution of kerosene emulsion and were set out on June 15. Only 30 plants were used in the test. None of these, when examined five days later, was found infested. There was apparently no injury to the plants from the kerosene. Two infested plants were

found in the check row of 30 plants. The number of plants treated was not large enough to make this test of much value.

In the second experiment kerosene was mixed with sand and a small amount sprinkled around 100 tobacco plants. One hundred plants in an adjoining row were used as a check. A light rain fell a few hours after the sand was applied. On June 18, eight days after treatment, the plants were examined. Sixteen were found injured in the treated row and 22 in the untreated row.

KAINIT.

In one experiment kainit was mixed with the soil in the hill before planting. Too large a quantity of the kainit was used in the test, as a considerable number of plants failed to grow. One hundred tobacco plants were put out in soil mixed with the kainit, and 100 plants in an adjoining row were left for a check. A number of infested plants were found where the kainit had been used, the substance evidently not being of much value as a preventive, as the worms often enter the plant at the "bud" or whorl of terminal leaves.

TURPENTINE.

In certain sections of Tennessee and Kentucky turpentine is said to have been used as a repellent for *Crambus* larvæ and cutworms. Before planting, the roots of the tobacco plants are dipped in water in which a small quantity of turpentine has been stirred.

A test on 1 acre of tobacco was made by Mr. Charles Armistead, of Clarksville, Tenn., and the field kept under observation by the writer. Entirely negative results were obtained. The following are details of the experiment: The tobacco was on weedy land containing an abundance of white top (*Erigeron annuus*) and plantain. The first planting was entirely destroyed. When the tobacco was replanted turpentine was used at the rate of 1 teaspoonful to 1 gallon of water, the roots of the plants being dipped in the mixture. On June 27, two weeks after planting, the tobacco was examined. Worms were still very numerous. Over 80 per cent of the plants had been entirely destroyed, in both treated and check plats. There seemed no apparent difference in infestation and damage between the treated tobacco and that on which no turpentine had been applied.

CALCIUM CYANAMID.

Calcium cyanamid (lime nitrogen) is said to have a repellent or poisonous effect upon insects, and on the suggestion of Mr. E. H. Mathewson, Crop Technologist of the Bureau of Plant Industry, Mr. B. G. Anderson, superintendent of the Tobacco Experiment Station at Appomattox, Va., and the writer made a test of the material during 1911, using the calcium cyanamid at the rate of 300 pounds per acre. The land selected had not been cultivated for several years. There was a rank growth of buckhorn plantain, oxeye daisy, and stickweed, and *Crambus* larvæ were exceedingly numerous, making conditions ideal for the test. The plat, containing one-twentieth of an acre, was divided into series of two rows each. The calcium cyanamid was used on two rows and the next two rows were kept as a check. On the treated rows commercial fertilizer at the following rate per acre was used:

	Pounds.
Calcium cyanamid.....	300
Acid phosphate.....	600
Sulphate of potash.....	100

On the check rows the fertilizer used (rate per acre) was as follows:

	Pounds.
16 per cent blood.....	300
Acid phosphate.....	600
Sulphate of potash.....	100

The calcium cyanamid analyzed about 17 per cent ammonia, this making the amount of plant food in the treated and check rows practically the same. The fertilizer was applied 14 days before the plants were set, as calcium cyanamid has the effect of stunting tobacco plants if applied directly before planting. It was applied to the rows with a drill, and thoroughly mixed with the soil by running a cultivator over the rows. The plants were set on June 8. By June 30 the plants in both treated and check rows had been almost completely destroyed by the *Crambus* larvæ, there being no indications of any beneficial effect from the calcium cyanamid in preventing injury. The tobacco was not replanted.

LEAD ARSENATE AND PARIS GREEN USED WITH COAL TAR ON SEED CORN TO PREVENT
INJURY BY CRAMBUS LARVÆ.

Experiments in the use of arsenate of lead and Paris green with coal tar on seed corn to prevent injury by *Crambus* larvæ were conducted in 1910 on the J. F. Purdum farm.

In experiment A, arsenate of lead in paste form was used at the rate of 1 ounce to 1 gallon of water. One peck of shelled seed corn was allowed to soak in the solution about 10 minutes and dried by mixing with fertilizer (acid phosphate). A very little coal tar (about a tablespoonful) was then poured on the corn, which was thoroughly stirred until a thin coating of the tar covered each kernel. Fertilizer was then used to dry the tar. With an ordinary planter one-half acre was planted in seed prepared as just described. Fully one-third of the corn failed to germinate, possibly owing to exclusion of moisture from the seed by the tar, as the weather was dry. No benefit in preventing injury by the worms seemed to result. In the check plat the stand of corn was practically perfect. On June 16, four weeks after planting, a count was made in the treated and check plats of hills of corn showing *Crambus* injury. Eleven per cent of the hills showed injury in the treated plat and 13 per cent in the check plat.

In experiment B, 1 ounce of Paris green was used to 1 peck of shelled seed corn. A small amount of tar (about one tablespoonful) was poured over the corn, which was thoroughly stirred until a thin coating of tar covered each kernel. The corn was then dried by mixing with fertilizer to which Paris green had been added. One-half acre was planted with seed prepared in this manner. About one-fifth of the seed failed to grow. In the check plat the stand was practically perfect.

A count of hills of corn showing *Crambus* injury, made on June 16, four weeks after planting, showed the results of the treatment to be as follows: Injury in treated plat, 11 per cent; injury in check plat, 9.5 per cent.

SUMMARY OF ECONOMIC CONTROL.

(1) The eggs of the tobacco *Crambus* are deposited in weedy fields during July and August. They hatch in a few days. The larvæ remain over winter in the soil and complete their growth during June and July. They are in their most active feeding stage at the time tobacco or corn is planted.

(2) Injury to tobacco or corn occurs when these crops are planted on land which was weedy during the previous year. Crops planted on land which has been under clean cultivation are immune from injury.

(3) The weeds which have been found to be the more common natural food plants of the worms are the buckhorn plantain, oxeye daisy, stickweed, and whitetop. The presence of these weeds in meadows accounts for injury to tobacco or corn when planted on sod.

(4) The worms when once established in land where their natural food plants are abundant have been found difficult to control.

(5) Various insecticides and repellents have been tested, but without satisfactory results.

(6) Fall or winter plowing has been found to reduce injury, but is only partially effective, as some of the weeds remain alive and furnish food for the larvæ until the tobacco or corn is planted.

(7) Damage is best prevented by crop rotations, or by cultural methods that prevent growth of the weeds which are food plants of the worms, thus making conditions unfavorable for egg deposition by the moths *the summer before tobacco or corn is planted*. Summer plowing, thorough preparation of weedy land, and the growing of crops of cowpeas or crimson clover, preferably cowpeas, the year before crops subject to injury are planted, have been found to be the most satisfactory and practical means of control.

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(PROFESSIONAL PAPER.)

RESEARCH STUDIES ON THE CURING OF LEAF TOBACCO.

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Investigations*.

INTRODUCTION.

The term "curing," as applied to tobacco, is somewhat indefinite in meaning, being used sometimes to include the separate operations of barn curing, fermentation, and aging, or afterfermentation, while the farmer usually restricts the term to the process of drying the ripe leaf in a specially constructed barn and under such conditions as will develop the desired properties or qualities. In the present article the term is used in the last-named more restricted sense, so that we have only to consider curing as far as it proceeds in the curing barn.

The methods now in vogue in barn curing are almost entirely empirical, being the result of practical experience extending through several generations, and in general are based more or less on rule-of-thumb procedures, without sufficient flexibility to meet changing conditions and requirements. The barn curing of tobacco has not received the attention from investigators that has been given the subsequent process of fermentation, and such investigations as have been made relate mostly to certain special phases of the subject.

There are two general methods of harvesting tobacco and arranging it in the barn which materially affect the results obtained in curing.¹ In the one case the leaves are picked from the stalk as they mature or "ripen" and are arranged on strings or sticks suitable for hanging in the curing shed, this method being popularly spoken of as priming. In the other method the leaves are not removed from the stalks, but the latter are cut off near the ground and suspended in an inverted

¹ For details of these methods consult Garner, W. W., *Principles and practical methods of curing tobacco*, U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 143, 54 p., 10 fig., 1909.

NOTE.—This bulletin gives the results of a study of the physiological changes occurring in curing tobacco in the barn and is of special interest to those concerned with the improvement of tobacco curing.

manner in the barn. There is an important modification of the method of harvesting and curing the leaves on the stalk in that, prior to being severed near the base, the stalk is split longitudinally from the top down the greater part of its length and when cut is placed astride a stick for hanging in the barn.

NATURE OF THE CURING PROCESS.

Observant growers well know that tobacco leaves which have been killed by freezing or by bruising do not cure normally, and a leaf which is quickly dried by heat does not possess the properties of the cured leaf. Moreover, if the fresh leaf is subjected for a few minutes to the action of protoplasmic poisons, such as formaldehyde or chloroform, it will not cure properly. It is quite evident, therefore, that curing is a life process and thus differs fundamentally from the subsequent fermentation, which takes place after the death of the leaf cells. That curing is essentially a life process can also be readily shown by chemical analysis, as is brought out in later paragraphs.

Curing materially changes the physical and chemical properties of the tobacco leaf, more particularly such properties or qualities as the capacity to hold fire, the color, the texture, and the elasticity. It does not develop the aroma, however. With respect to the development of some of the above-mentioned properties of the leaf, fermentation may be regarded as supplementary to curing; but, as we hope to show more fully in a later publication, some of the important changes in composition involved in curing are not continued in the fermentation, so that incomplete curing can not be fully corrected in the subsequent fermentation.

As will be shown later, curing involves principally the two familiar physiological processes of respiration and of the translocation of mobile nutrients. Some investigators have preferred to regard the respiration phenomena as essentially pathological in character, and this view seems logically correct. The stalk and its leaves or the leaves alone, as the case may be, after harvesting are deprived of the water solution from the root system and for the most part are deprived of sunlight. Since respiration continues, the living cells of the leaf are subjected to a process of starvation, and the degree to which the starvation proceeds is largely dependent on the rate of drying. As a matter of fact, however, the general character of the changes in composition during the curing, due to respiration, is very much the same as in normal respiration. As would be expected, the prevailing temperature and humidity play an important rôle in the process. The other important phenomenon, translocation, involves the movement of soluble materials from the leaf web, through the veins, into the midrib, and, if the leaf is attached to the stalk, thence into the latter. With one or two exceptions, investigators have over-

looked the importance of translocation when the leaf is cured on the stalk.

It is, of course, well known that during the growth and development of the plant there is a movement of the products of photosynthesis, rendered soluble by enzymes when necessary, from the more mature leaf through the stalk to the younger growing parts. Essentially the same thing takes place after the cut plant has been placed in the barn, except that the materials transported are derived wholly from the surplus food supply of the leaf. While the leaf web perishes in a few days, the midrib remains alive for longer periods and the stalk may remain perfectly green for several weeks. Secondary shoots, or suckers, developing in the leaf axils, may be found growing at the end of several weeks, and the necessary food supply for the stalk and the suckers is derived from the leaf surplus. An interesting confirmation of this phenomenon is found in the case of excessive moisture prevailing in the barn during the later stages of curing, a condition which leads to the decay of the leaf known as pole-sweat. The excessive moisture causes the dying leaf cells to retain more water, thus facilitating the more complete translocation of food materials into the stalk. Under these circumstances the so-called absciss-layer is formed at the juncture of the midrib with the stalk, so that the leaf is cast off as a useless appendage. Under normal curing conditions the leaves remain firmly attached to the stalk.

LOSS IN WEIGHT OF DRY MATTER IN AIR CURING WHEN THE LEAF IS PRIMED.

The first problem met with in a physiological study of curing is the total loss in dry weight which occurs in the process. So far as we know, no accurate determinations have been previously made on this point, at least in this country. Because of the important rôle of translocation in curing, the loss in weight depends largely on the method used in harvesting the tobacco. So far as it relates to loss in weight of the whole leaf, translocation can play no part when the leaf is separated from the stalk in harvesting.

Our experiments cover the crop years of 1908 to 1911, inclusive, a period of four years, and were confined to the cigar-wrapper-leaf section of Connecticut, the experimental material all being obtained from the farm of W. S. Pinney, Suffield, Conn. The types of tobacco included in the experiments are the Havana Seed, the Halladay, and a so-called John Williams broadleaf. The Havana seed is one of the old standard types of domestic cigar-wrapper leaf and the Halladay is a new type developed from a cross of Havana seed on Sumatra. The history of the John Williams type of broadleaf is not known, but it differs decidedly from the ordinary broadleaf, and its habits of growth strongly suggest its origin from a cross of the latter on Cuban.

In gathering the experimental material each year, a sufficient number of representative plants was selected to give about 200 ripe leaves near the bases of the plants, six or eight leaves being taken from each plant. The leaves were taken in pairs, each alternate leaf being placed in one lot and the other leaves in a second lot, the aim being to have each leaf in the one lot represented by a duplicate in the second lot. For the success of the experiment it is essential that the total dry weight and also the average composition of the two lots of leaves be practically the same. The detailed examination of the material gathered in the manner described indicates that these requirements have been satisfactorily met. As promptly as possible after harvesting the leaves the midribs were completely removed from the lot which was used to obtain the original dry weight. This was done to prevent any flow of cell sap between the leaf web and the midrib during the drying. The split leaves as well as the midribs were at once placed in a large drying oven and maintained at a temperature of about 80° C. until all were completely dry. The temperature employed rapidly kills the protoplasm, and comparative tests with other methods of killing, such as plunging in boiling absolute alcohol, showed that the respiration changes during the drying were too small to be of significance for our purposes. (See p. 35.) The dry weights of the leaf web and the midribs were obtained and the material preserved for analysis. The second lot of leaves was placed in the barn for curing in the usual way without removing the midribs. When the cured leaves were ready for examination the leaf web was removed from the midrib, the dry weights obtained, and the material preserved for analysis.

As has been stated, observations were made for a period of four consecutive years of the loss of dry matter in curing when the leaves are harvested by picking them from the stalk. The detailed results of these experiments are shown in section A of Table I (p. 5). In the case of the 1908 material the curing was stopped before the midribs had cured, but the curing of the leaf web was practically complete. In 1910 a special test of partial curing was made (Table I, fourth column) and in this case the curing was stopped while the larger veins and midribs were still uncured. In 1911 a test was made of the effect of artificial heat on the curing.

TABLE I.—*Loss in dry weight in air curing tobacco leaves: (A) by the priming method, (B) by curing on the stalk.*

Tobacco leaves.	A.—Leaves cured by the priming method.								
	Havana Seed; 1908 (partially cured).			Halladay; 1909.			Halladay; 1910.		
	Leaf web.	Stems.	Whole leaf.	Leaf web.	Stems.	Whole leaf.	Leaf web.	Stems.	Whole leaf.
Weight of 100 dry leaves:									
Uncured.....grams..	409.5	155.1	564.6	335.2	117.2	452.4	294.8	121.4	416.2
Cured.....do.....	329.4	157.5	486.9	306	98	404	256.4	98.6	355
Loss of weight in curing, per cent.....	19.6	¹ —1.6	13.8	8.7	16.4	10.9	13	18.8	14.7
Leaves:									
Uncured.....per cent..	72.5	27.5	100	74.1	25.9	100	70.8	29.2	100
Cured.....do.....	67.6	32.4	100	75.7	24.3	100	72.2	27.8	100
Weight of pure ash in 100 leaves:									
Uncured.....grams..	44.9	26.9	71.9	51.2	26.7	77.9	38.4	23.3	61.7
Cured.....do.....	43.9	26.3	70.2	55.3	25.2	80.5	41.4	22.2	63.6
Apparent gain or loss of ash in curing.....per cent..	— .24	— .38	— .29	+1.20	—1.28	+ .57	+1.02	— .91	+ .45
Loss of organic matter in curing ¹.....per cent..	19.6	¹ —1.6	13.8	9.6	14.3	10.9	13.6	17.3	14.7

Tobacco leaves.	A.—Leaves cured by the priming method.								
	Halladay; 1910 (partially cured).			John Williams broadleaf.					
	Leaf web.	Stems.	Whole leaf.	1911-A (artificial heat applied).			1911-B (no artificial heat applied).		
				Leaf web.	Stems.	Whole leaf.	Leaf web.	Stems.	Whole leaf.
Weight of 100 dry leaves:									
Uncured.....grams..	269.3	120.7	390	402	114.8	516.8	402	114	516
Cured.....do.....	234.3	108.3	342.6	356.8	87.6	444.4	356.5	87.8	444.3
Loss of weight in curing, per cent.....	13	10.3	12.2	11.2	23.7	14	11.3	23	13.9
Leaves:									
Uncured.....per cent..	69.1	30.9	100	77.8	22.2	100	77.9	22.1	100
Cured.....do.....	68.4	31.6	100	80.3	19.7	100	80.4	19.6	100
Weight of pure ash in 100 leaves:									
Uncured.....grams..	34	22.3	56.4	48.9	23.8	72.7	48.3	24.2	72.5
Cured.....do.....	36.3	21.4	57.6	53.4	21	74.4	52.2	20.9	73
Apparent gain or loss of ash in curing.....per cent..	+ .85	— .74	+ .31	+1.12	—2.43	+ .33	+ .97	—2.89	+ .11
Loss of organic matter in curing.....per cent..	13.5	9.1	12.2	12.1	19.1	14	12.2	19.9	13.9

¹ Represents gain.² These figures are arrived at by deducting from the total loss in weight the apparent translocation of ash between leaf tissue and stem. See page 6.

TABLE I.—*Loss in dry weight in air curing tobacco leaves: (A) by the priming method, (B) by curing on the stalk—Continued.*

Tobacco leaves.	B.—Leaves cured on stalk.								
	Havana Seed; 1908 (partially cured).			Halladay; 1909.			Halladay; 1910.		
	Leaf web.	Stems.	Whole leaf.	Leaf web.	Stems.	Whole leaf.	Leaf web.	Stems.	Whole leaf.
Weight of 100 dry leaves:									
Uncured.....grams..	437.1	165.9	603	342.9	145.4	488.3	297.6	123.1	420.7
Cured.....do.....	312.4	134	446.4	238.1	104.6	342.7	230	86.7	316.7
Loss of weight in curing, per cent.....do.....	28.6	19.2	26	30.6	28.1	29.8	22.7	29.6	24.7
Leaves:									
Uncured.....per cent..	72.5	27.5	100	70.2	29.8	100	70.7	29.3	100
Cured.....do.....	70	30	100	69.5	30.5	100	72.6	27.4	100
Weight of pure ash in 100 leaves:									
Uncured.....grams..	45.3	28.4	73.7	42.3	27.9	70.1	38.6	23.2	61.9
Cured.....do.....	41.4	26.4	67.8	40.3	23.1	63.4	37.3	18.6	55.9
Loss of ash in curing, per cent.	.89	1.20	.98	.59	3.31	1.38	.43	3.74	1.42
Loss of organic matter in curing.....per cent..	27.7	18	25	30	24.8	28.4	22.3	25.9	23.3

The content of pure ash is of special interest as serving as a check on the original uniformity in size and composition of the uncured and cured leaves of each series, since there could be no actual loss of ash from the whole leaf. The differences found between the uncured and the cured leaves are so small as to be negligible, and they furnish strong evidence of the uniformity in size and composition of the original duplicate samples. We are safe, therefore, within very narrow limits, in regarding the observed differences in weight between the uncured and cured leaves as representing the true loss in weight of dry matter during the curing process.

Regarding the total loss in weight of the whole leaf, it will be seen that the values ranged from about 11 to about 14.5 per cent when the curing was completed. In the case of the 1909 sample of Halladay tobacco the loss is undoubtedly below normal, and the low value for the whole leaf is due mainly to the slight loss in weight of the leaf web. It is not known to what extent unfavorable weather conditions during the curing may have influenced the result, but by reference to Table IV, section A (p. 18), it will be seen that the sample was very low in starch content, and this constituent is the most important of all as regards loss in weight in curing. (See also p. 31.) Disregarding this sample, the loss in weight in the experiments is surprisingly uniform in view of the differences in types of leaf and the varying weather conditions during the curing. In the two cases where the curing was interrupted before it was complete, the loss in weight of the whole leaf was nearly as great as in complete curing, showing that the principal changes in composition to which the loss in weight is due proceed rapidly. In the case of the Havana Seed

sample (1908) the loss would undoubtedly have been considerably greater had the stems been permitted to cure, as is to be expected, because of the relatively high starch content in this sample. For the types of leaf considered, the average loss in weight in dry matter during the curing of the picked leaves may be placed at about 12 to 15 per cent.

The data presented in Table I, section A, relate only to types of tobacco adapted to and grown under conditions favorable to the production of cigar-wrapper leaf, which is relatively very thin and light. This class of tobacco is harvested in a less ripe condition than are other classes of leaf, so that a lower content of starch is to be expected in the leaves when harvested. For these reasons the loss in dry weight in curing is greater in other classes of tobacco, and in the case of the export types losses in weight as high as 38 to 40 per cent have been observed. The loss in weight in curing varies with the variety or type grown, the conditions under which the tobacco is grown, the degree of ripeness when it is harvested, and also with the conditions under which the curing takes place. The effects of these factors on the loss in weight are due to their influence on the composition of the leaf before or after the curing, particularly on the content of starch.

LOSS IN WEIGHT OF DRY MATTER IN AIR CURING WHEN THE LEAF IS CURED ON THE STALK.

The experiments relating to the loss in weight when the leaves are cured on the stalk cover the crop years of 1908 to 1910, inclusive, a period of three years, and the experimental material was obtained from the same fields as was that used in the preceding experiments. The stalks of the plants used were not split in harvesting, but were hung in the barn in the usual manner for curing cigar tobaccos. Every effort was made to have the experimental material directly comparable with that used in the preceding experiments for the same years. Plants were selected which were as nearly as possible like those used for the experiments in priming. Beginning near the base of the plant each alternate leaf was picked off, taking three or four leaves from each plant and leaving all of the remaining leaves intact. The stalks were then harvested and placed in the barn for curing. The midribs were promptly removed from the picked leaves and both the leaf web and the midribs completely dried, as in the previous experiment. The dry weights of the leaf parts were recorded and the material preserved for analysis. When the leaves attached to the stalks were cured the weights of the leaf web and midribs were likewise obtained and the material kept for further examination. As in the case of the experiments in priming, the leaves were removed from the stalks in the 1908 experiment before the midribs were fully cured. With the possible exception of the 1909 material, the

ash content and the ratio of leaf web to rib in the uncured leaves, as well as the detailed analyses later reported, show conclusively that the original samples used for stalk curing were very similar to the corresponding samples used in curing by priming.

The results of the three-year experiment are set forth in detail in section B of Table I. It will be seen at a glance that the loss in weight of the whole leaf in curing on the stalk is far greater than when the leaves are separated from the stalks. The figures run from about 25 to 30 per cent, or approximately double those for curing the picked leaves. In the 1908 sample the total loss in weight would have been somewhat greater had the stems been given sufficient time for complete curing. The loss in weight in stalk curing is greater in both leaf web and rib than when the picked leaves are cured. It will be seen that the apparent loss in pure ash is positive and marked in all cases in both the leaf web and the ribs, showing conclusively that a portion of the ash passes into the stalk during the curing.

EFFECT OF SPLITTING THE STALK ON THE LOSS OF WEIGHT IN AIR CURING.

In some tobacco districts the stalk is split longitudinally from the top down the greater part of its length at the time the plant is harvested. Under these conditions the stalk can not remain alive in the barn as long as when it is merely severed from the rootstock, and it is to be expected that the phenomenon of translocation would be less important. A special experiment was carried out to secure information on this point.

Two similar lots of 10 plants each were selected, and the stalks of one lot were split in the manner followed by growers. Each alternate leaf was picked from the plants in both lots, and the two lots of leaves thus obtained were cured separately. The leaves remaining on the stalks were cured under the same conditions as the primed leaves. When the curing was complete the dry weights were obtained as in the preceding experiments. At that time the unsplit stalks were still green, while the split stalks had largely dried out.

TABLE II.—*Loss of dry weight in air curing as affected by splitting the stalk in harvesting.*

Air-cured leaves.	Stalks split in harvesting.			Stalks not split in harvesting.		
	Leaf web.	Stems.	Whole leaf.	Leaf web.	Stems.	Whole leaf.
Weight of 50 leaves:						
Cured on stalk.....grams..	177.9	70.1	248	176.5	68.3	244.8
Cured after picking.....do....	219.5	81.1	300.6	227	84.6	311.6
Difference in loss of weight between stalk curing and curing picked leaves, per cent	18.9	13.6	17.4	22.2	19.3	21.4
Leaves consisted of:						
Cured on stalk.....per cent..	71.8	28.2	.....	72.1	27.9	.....
Cured by picking.....do.....	73	27	.....	72.8	27.2	.....

The results of the experiment are shown in Table II. While the actual number of leaves in each lot was 58, the results are calculated on a basis of 50 leaves for convenience in comparing with the other experiments. The experiment, of course, does not show the total loss in weight in curing in any case, but other experiments with similar material from the same field indicate that the loss in weight of the picked leaves must have been more than 20 per cent. The type of tobacco and the stage of ripeness account in all cases for the larger losses in weight than were obtained with the cigar types. Since only a single experiment was made and a rather small number of leaves used, the results can be taken as only approximately correct. These results indicate that when the stalk is split in harvesting, the loss in weight in curing is less than when the stalk is not split, but, nevertheless, the loss is much greater than when the leaves are picked from the stalk.

COMPOSITION OF CIGAR-WRAPPER LEAF BEFORE AND AFTER CURING.

The material obtained in connection with the data presented in Table I was subjected to analysis to ascertain the nature of the changes in composition which take place in air curing and to which the losses in dry weight are due. Because of the variations in the composition of the leaf at the time of harvesting, it is obviously essential that the material chosen for study shall be obtained under such conditions as will insure original uniformity in the composition of the uncured and cured samples. That this has been very closely attained in the above-mentioned material is shown in the values obtained for those constituents which undergo no change in the curing.

LEAF HARVESTED BY PRIMING.

The samples¹ used in these experiments cover the curing seasons of 1908 to 1911, inclusive, and include cases in which the curing was not fully completed. Although the midrib is never removed prior to curing, it has little or no value in manufacturing and, moreover, differs decidedly in composition from the leaf web, so that for present purposes it is necessary to consider the two leaf parts separately. The cured leaf always contains more or less water, depending on the type in question and on atmospheric conditions, but to simplify matters all results have been calculated to a water-free basis.

PREPARATION OF MATERIAL AND METHODS OF ANALYSIS EMPLOYED.

To pulverize the material for analysis, the leaf web was simply passed through a 60-mesh wire sieve. The stems were prepared by grinding to a fine powder in an iron mortar. The water content of the sample was determined by drying over sulphuric acid, as recommended by

¹ For details as to the methods followed in selecting and gathering the samples, the type of leaf used, etc., see p. 3.

Kissling. The pure ash, the carbohydrates, including starch, reducing sugars, pentosans, and crude fiber, and the several nitrogenous constituents were determined by the following methods:

Pure ash.—The tobacco was incinerated in the usual manner in a platinum dish with a cover, care being taken to avoid fusing the ash. The pure ash is obtained by correcting for carbon dioxid, carbon, and sand.

Starch.—Rather than attempt to determine starch directly by the diastase method it was preferred to obtain the total of the carbohydrates hydrolyzed by hydrochloric acid, using the official method, and to determine also the pentosans. It is thought that for purely comparative results this method is satisfactory, and nearly all previous analyses of tobacco for starch which the writers have seen have been based on this method of the direct hydrolysis with acid, but usually without determining the pentosans.

Pentosans.—The determinations were made by the official method, the phloroglucin being calculated to pentosan by Kröber's tables.

Reducing sugars.—Since nicotine, even in a moderately concentrated solution, exerts a reducing action on Fehling's solution, it is removed before preparing the solution for the determination of reducing sugars. This is done by moistening 5 grams of the tobacco with 5 c. c. of a 5 per cent solution of caustic potash in absolute alcohol and digesting the mixture in a flask with 100 c. c. of absolute ether. The reducing sugar is then extracted with 60 per cent alcohol, the alcohol removed by evaporation, the water solution made up to volume, clarified with normal lead acetate, and the sugar determined as glucose by the Allihn method.

Crude fiber.—The official method, as modified by Sweeney and by Kennedy, was employed.

Nonvolatile organic acids.—The method of Kissling¹ was followed for the determination of oxalic, citric, and malic acids. We have found it necessary, however, to increase by at least 25 per cent the quantity of sulphuric acid recommended by Kissling to be added to the tobacco, to insure the liberation of all the organic acids. This was particularly true of the cured samples, from which only very small portions of the oxalic acid could be extracted when only 10 grams of a 20 per cent sulphuric-acid solution were added to 10 grams of the tobacco.

Protein nitrogen.—Tests having shown that the method of Mohr² gives excellent results for the purpose in view, it was followed in preference to the official (Stutzer) method. In this process the tobacco is simply boiled with a dilute acetic-acid solution, filtered

¹ Kissling, Richard. Beiträge zur Chemie des Tabaks. Zur Tabakanalyse. Chemiker-Zeitung, Jahrg. 28, No. 66, p. 775-776, 1904.

² Mohr, E. C. J. Gepflückter und am Stamme getrockneter Tabak. Die Landwirtschaftlichen Versuchs-Stationen, Bd. 59, p. 274, 1903.

cold, and, after washing with hot water acidified with acetic acid, the nitrogen in the residue is determined by the Kjeldahl method. Comparative tests of cured and uncured samples of tobacco show that the Stutzer method regularly gives results about 0.2 per cent higher than the Mohr method. The protein is estimated by multiplying the nitrogen obtained as indicated by the usual factor, 6.25.

Nicotine.—This constituent was determined by the method described in Part VII of Bureau of Plant Industry Bulletin No. 102, entitled "A New Method for the Determination of Nicotine in Tobacco," tests having shown that this process gives as accurate comparative results as does the well-known Kissling method.

Nitric acid.—The method of Kissling¹ was followed in this determination.

Ammonia.—This constituent was determined in the filtrate from the protein nitrogen by the Folin method as modified by Pennington and Greenlee.² Under the conditions, only traces of nicotine are carried over into the receiver by the air current. However, in our determinations the results were corrected by running check solutions containing the same quantities of nicotine as were known to be contained in the solutions from the tobacco samples. The temperature, rate of air current, etc., were kept as uniform as possible in making the determinations.

Amid and amido nitrogen.—This value was obtained by taking the difference between the total nitrogen and the sum of the protein, nicotine, nitrate, and ammonia nitrogen. The figure obtained was multiplied by 4.8 (the approximate factor for asparagin) for amid and amido compounds.

Total nitrogen.—The official Gunning method, as modified for nitrates, was used.

RESULTS OBTAINED IN THE FOUR-YEAR EXPERIMENT.

In section A of Table III (p. 12) will be found the results of the analyses of the leaf samples previously described. The leaf web and the stems or midribs were, of course, analyzed separately, and the results for the whole leaf were calculated from the ratio of leaf web to stem in each case. As a matter of convenience, the ripe, uncured leaf is designated in the table as "green."

The content of pure ash of the cured leaves is higher than that of the uncured leaves in proportion to the loss in dry weight in curing, since there can be no change in the quantity of ash during the curing. While the green leaves contain considerable but quite variable quantities of starch, the cured leaves contain practically none, as shown by

¹ Kissling, Richard. Handbuch der Tabakkunde, des Tabakbaues und der Tabakfabrikation. Aufl. 2, Berlin, 1905, p. 78.

² Pennington, M. E., and Greenlee, A. D. An application of the Folin method to the determination of the ammoniacal nitrogen in meat. Journal, American Chemical Society, v. 32, p. 561-568, 1 fig., 1910.

TABLE III.—Composition of cigar-wrapper leaf before and after curing.

A.—LEAVES CURED BY THE PRIMING METHOD.

[illegible]

Constituents.	Halladay, 1910 (partially cured).						John Williams broadleaf.										
	Leaf web.		Stems.		Whole leaf.		1911-A (artificial heat applied).		1911-B (no artificial heat applied).		Whole leaf.						
	Green.	Cured.	Green.	Cured.	Green.	Cured.	Leaf web.		Stems.		Whole leaf.						
							Green.	Cured.	Green.	Cured.	Green.	Cured.	Green.	Cured.			
Pure ash.....	12.64	15.47	18.48	19.73	14.40	16.78	12.16	14.97	20.72	24.02	16.75	12.02	14.62	21.21	23.93	14.05	16.46
Starch ¹	7.74	5.02	7.87	7.44	7.78	5.79	7.54	4.93	9.41	8.30	7.96	5.86	5.07	10.60	9.93	6.91	6.03
Sugars.....							1.64	2.37	8.40	0.05	3.14	2.33	1.30	2.25	0.06	2.77	2.71
Pentosans.....							7.54	4.93	8.45	8.95	5.55	6.05	4.78	5.23	9.88	5.77	6.15
Cellulose (crude fiber).....							4.72	5.34	13.87	17.03	10.53	10.98	12.09	14.46	18.18	11.75	13.28
Oxalic acid.....							7.82	8.94	2.79	2.79	1.96	2.50	2.32	2.80	1.55	2.11	2.55
Citric acid.....							2.19	2.79	1.15	1.30	1.96	2.50	2.32	2.80	1.36	2.11	2.55
Malic acid.....							8.52	13.83	2.32	4.45	7.14	11.98	9.52	15.20	2.46	5.13	7.96
Malic acid.....							6.89	5.17	6.87	3.81	6.66	4.90	7.28	4.51	5.96	2.55	6.59
Protein ²	21.0	10.75					22.56	9.81	4.63	4.87	18.56	8.84	21.19	9.08	4.38	4.75	17.50
Nicotine.....							3.29	3.43	5.88	7.38	2.69	2.91	3.74	3.67	8.82	3.06	2.96
Nitric acid (N ₂ O ₅).....							1.07	1.54	8.62	9.30	2.75	2.95	3.43	8.00	7.89	2.44	2.72
Ammonia.....							.07	.45	.05	.32	.42	.03	.61	.04	.23	.03	.55
Amid and amido compounds ³							3.60	12.53	0	3.17	2.80	10.68	4.32	10.70	0	2.06	3.37
Total nitrogen.....							5.27	5.53	3.03	4.25	4.77	5.32	5.18	5.19	2.84	3.41	4.66
Undetermined ⁴							22.65	21.34	24.38	22.60	21.72	20.57	20.08	22.92	22.86	21.06	20.61

* Includes total carbohydrates hydrolyzed by dilute acid.

2 Protein nitrogen $\times 6.25$.

* Total nitrogen less nitrogen as protein, nicotine, nitric acid, and ammonia $\times 4.8$. With two exceptions (1908) the sums of the protein, nicotine, nitrate, and ammonia nitrogen of the green stems exceed slightly the values obtained for total nitrogen. For the probable explanation, see text (p. 28).

⁴ Pentosans and total nitrogen are not included in the calculation of this value.

TABLE III.—Composition of cigar-wrapper leaf before and after curing—Continued.

B.—LEAVES CURED ON THE STALK.

Constituents.	Havana Seed, 1908 (partially cured).						Halladay, 1909.						Halladay, 1910.					
	Leaf web.		Stems.		Whole leaf.		Leaf web.		Stems.		Whole leaf.		Leaf web.		Stems.		Whole leaf.	
Pure ash.....	10.36	13.28	17.14	19.67	12.22	15.20	12.32	16.91	19.18	22.10	14.36	18.49	12.98	16.22	18.87	21.50	14.70	17.67
Starch ¹	16.97	6.56	10.64	10.52	15.23	7.75	8.22	7.59	12.41	9.29	9.47	8.13	6.14	6.27	8.23	7.78	6.75	6.08
Sugars.....	2.29	2.97	8.57	4.37	4.01	3.39	1.89	.64	9.77	.24	4.24	.52	1.02	0	8.69	0	3.26	0
Pentosans.....	4.45	5.81	8.04	9.43	5.44	6.90	4.61	6.59	8.54	8.65	5.78	7.30						
Cellulose (crude fiber).....	7.28	10.98	13.00	16.37	8.85	12.60												
Oxalic acid.....	1.60	2.52	1.29	1.51	1.51	2.21												
Citric acid.....	5.45	13.95	4.41	5.29	5.16	11.35												
Malic acid.....	9.21	6.77	9.70	10.06	9.34	7.76												
Protein ²	13.12	7.25	3.87	3.81	10.56	6.19	22.40	16.05	4.63	4.25	17.05	12.50	20.00	11.13	4.44	4.31	15.44	9.25
Nicotine.....	4.11	5.21	.87	.55	3.21	3.71	2.17	2.32	.45	.45	1.66	1.74	1.53	1.89	.22	.17	1.15	1.42
Nitric acid (N ₂ O ₅).....	.11	.08	1.60	1.61	.52	.06	1.75	2.61	9.92	9.99	4.18	4.90	1.11	2.15	11.02	11.11	4.01	4.59
Ammonia.....	.07		0	.03	.05													
Amid and amido com- pounds ³	3.46	3.26	1.58	1.54	2.98	2.74	2.35	1.05	0	0	1.65	.74	7.25	7.68	0	.91	5.13	5.54
Total nitrogen.....	3.61	2.82	1.51	1.46	3.03	2.41	4.91	3.87	3.03	3.39	4.34	3.72	5.25	4.28	3.21	3.32	4.65	4.05
Undetermined ⁴	25.97	26.95	27.33	22.67	26.36	26.38												

¹ Includes total carbohydrates hydrolyzed by dilute acid.² Protein nitrogen $\times 6.25$.³ Total nitrogen less nitrogen as protein, nicotine, nitric acid, and ammonia $\times 4.8$. With two exceptions (1908) the sums of the protein, nicotine, nitrate, and ammonia of the green stems exceed slightly the values obtained for total nitrogen. For the probable explanation, see text (p. 28).⁴ Pentosans and total nitrogen are not included in the calculation of this value.

the iodine test. Cigar-wrapper-leaf types contain less starch at the time of harvesting than other commercial types of leaf, because the former are harvested at a less mature stage and are produced under conditions less favorable to the accumulation of starch during the ripening period. Müller-Thurgau¹ has shown that in some cases fully ripe European-grown tobacco leaves may contain upward of 40 per cent of starch, and we have found this to be true of some samples of our export types. (Compare pp. 35 and 38).

One of the most marked physiological differences between the green and cured leaves is the content of protein insoluble in dilute acid. In all cases the protein content of the cured leaves is much less than that of the uncured leaves.

The content of nitric acid in the green and in the cured leaves is about the same. The green leaves at most contain only traces of ammonia, while the cured leaves contain considerable quantities. The cured leaves contain relatively much larger quantities of amid and amido compounds than the green leaves. The relative content of total nitrogen is somewhat less in the green than in the cured leaves.

LEAF HARVESTED ON THE STALK.

The method followed in the preparation of the material and the methods of analysis employed were the same as for the leaves harvested by priming. The original material was chosen with a view to obtaining samples which would be duplicates, essentially, of those used in the preceding experiments, in order that the stalk-cured leaves might be strictly comparable with those cured after being picked from the stalk. It is, of course, a simple matter to check by analysis the original uniformity of the corresponding lots of the green leaves in each case, since these were detached from the stalks, the leaf web separated from the midribs, and the leaf parts quickly dried. This can not be done so readily, however, with the two lots of cured leaves, because of the fact that when the leaves are cured on the stalk there is a well-defined movement of certain constituents from the leaf into the stalk, causing an additional loss in weight, which can only be determined by direct experiments, as reported in Table I, which require that the green and the cured leaves shall possess the same original weight.

RESULTS OBTAINED IN THE THREE-YEAR EXPERIMENT.

The comparative composition of cigar-wrapper leaf cured on the stalk and of the corresponding uncured leaf is shown in section B of Table III. As in the primed leaves, the ash content of the whole leaf is higher in the cured than in the uncured leaves. The cured leaves

¹ Müller, Hermann (*Thurgau*). Ueber das Verhalten von Stärke und Zucker in reifenden und trocknenden Tabaksblättern. Landwirthschaftliche Jahrbücher, Bd. 14, p. 485-512, 1885.

are again practically free from starch and reducing sugars, except where the curing was incomplete. The difference as regards protein is similar to those noted in the cured and uncured leaves in the preceding experiments. The differences with reference to amid and amido compounds are somewhat variable, but it is evident that the cured leaf does not contain appreciably larger quantities of these constituents, relatively, than the green leaf, and the same is true as to ammonia. It is clear that the cured leaves contain considerably less total nitrogen than the green leaves.

Analyses of cured samples of our more important commercial types of leaf tobacco have been published by several investigators,¹ but none of them has included the comparative composition of the corresponding uncured leaf. The results of Moore and of Carpenter indicate that the cured leaf of the bright flue-cured type is quite low in ash content, and it should be added that we have had occasion to examine a number of samples grown in eastern North Carolina which contained only 6 or 7 per cent of crude ash in the leaf web. In this type the cured leaf appears to be practically free from starch, but the content of reducing sugars is quite high (16 to 18 per cent), while the content of cellulose is decidedly low, particularly in the leaf web. The leaf contains moderate quantities of nicotine, practically no nitrate, and is very low in protein, as would be expected from the light color. White Burley, which is an air-cured type, is uniformly high in ash content, according to these authors. The cured leaf appears to be free from starch and reducing sugars and is relatively high in content of cellulose. The content of nicotine is high, the content of nitrate is considerable, and the content of protein is high. It is interesting to note that Burley closely resembles the cigar-wrapper-leaf types in composition in respect to all of the above-mentioned constituents. It is also interesting to note that the peculiar chlorotic appearance of this type when growing in the field is not associated with a low content of organic nitrogenous substances. The dark fire-cured export types of Virginia, Kentucky, and Tennessee are rather high in ash content, free from starch, low in reducing sugars,² and somewhat low in cellulose. These types are quite high in nicotine, usually low in nitrate, and high in protein, as is to be expected from the dark color of the cured leaf. The one sample of

¹ Moore, G. E. Report on the chemistry of American tobaccos. In Killebrew, J. B., Report on the culture and curing of tobaccos in the United States, p. 269. U. S. Department of the Interior, Census Office, Report on the Productions of Agriculture, Tenth Census, 1880. 1883.

Chemical changes in tobacco during fermentation. Connecticut Agricultural Experiment Station, 16th Annual Report, 1892, p. 29-30. 1893.

Winton, A. L., Ogden, A. W., Mitchell, W. L., and Jenkins, E. H. Effects of fertilizers on the composition of wrapper leaf tobacco. Connecticut Agricultural Experiment Station, 20th Annual Report, 1896, p. 325-326. 1897.

Carpenter, F. B. Types of tobacco and their analyses. North Carolina Agricultural Experiment Station, Bulletin 122, p. 331-366, 1895.

² Only two samples reported as to starch and sugars.

Maryland export leaf reported is of interest chiefly because of its unusually high content of cellulose, since this type is characterized by its "chaffiness." The analyses of cigar-wrapper leaf reported by Jenkins and Winton are fairly comparable with our results, shown in Table III, since the material was grown in the same locality and the results obtained in the two cases are not essentially different.

CHANGES IN COMPOSITION OF LEAF TOBACCO IN AIR CURING.

While the data presented in Table III show the comparative composition of cured and uncured leaf tobacco in the form there presented, they do not properly bring out the changes in composition which take place during the curing. As shown in Table I, there is a marked but variable loss of dry weight in curing, and it is evident that the simple comparison of the percentage composition of cured and uncured leaves does not give a correct index as to the actual changes in content of the various constituents involved in the curing. As pointed out by Mohr,¹ nearly all early investigators have made this error in collecting their data, with the result that many of their conclusions are entirely erroneous. There are two ways in which this difficulty can be overcome. One method is to base all comparisons on unit areas of the leaf rather than on weights, and this is undoubtedly the most satisfactory method in dealing with a small number of leaves, but where larger quantities of material are required the procedure requires much time and labor. A second method, which has been followed in our experiments, is to collect the leaves in pairs, so that each leaf which is cured shall have a duplicate which is quickly dried and weighed, as was described on page 4. In this way the total loss in weight in curing is obtained simply by comparing the weights of the cured and uncured leaves, and it is only necessary to correct the results of the analysis of the cured leaves for the total loss of weight in curing. There are necessarily some individual variations in the leaf "pairs," so that this method is not entirely reliable when only a few leaves are used, but if the composite samples include a hundred or more leaves the individual variations are of little or no consequence.

In Table IV we have corrected the results of the analyses of the cured leaf as shown in Table III for the respective loss in weight in the curing of each sample as shown in Table I, so that all results are calculated on the basis of the uncured leaf. We have added data showing the gain or loss of each constituent for the two leaf parts and for the whole leaf in each case. Table V presents in a similar manner the data for the total nitrogen and nitrogen in the various forms of combination found in the tobacco.

¹ Mohr, E. C. J. *Gepflückter und am Stamme getrockneter Tabak*. Die Landwirtschaftlichen Versuchs-Stationen, Bd. 59, Heft 3/4, p. 256, 1903.

TABLE IV.—*Percentage of gain or loss of each constituent which takes place in air curing tobacco.*
 [Calculated from the results shown in Tables I and III.]

Constituents.	A.—Leaves cured by the priming method.											
	Havana Seed; 1908 (partially cured).						Halladay; 1909.					
	Leaf web.			Stems.			Leaf web.			Stems.		
	Green.	Cured.	Gain or loss.	Green.	Cured.	Gain or loss.	Green.	Cured.	Gain or loss.	Green.	Cured.	Gain or loss.
Pure ash.....	10.97	10.73	— 0.24	17.35	16.97	— 0.39	15.28	16.49	+ 1.21	22.78	21.48	— 1.30
Starch ¹	16.32	5.56	—10.82	10.82	8.95	— 1.87	5.77	4.36	— 1.41	9.94	6.91	— 3.03
Sugars.....	3.32	2.76	— 0.56	10.40	12.09	+ 1.69	1.33	.55	— .78	9.78	.55	— 9.23
Pentosans.....	4.21	4.30	+ .09	7.91	7.81	— .10	4.84	4.88	+ .04	7.48	6.41	— 1.07
Cellulose (crude fiber).....	8.50	8.22	— .28	13.12	13.43	+ .31	9.77	9.65	— .12	.....	.....	.....
Oxalic acid.....	1.54	1.75	+ .21	1.27	1.08	— .19	1.47	1.57	+ .10	.....	.....	.....
Citric acid.....	5.88	8.74	+ 2.86	3.54	2.81	— .73	5.24	7.11	+ 1.87	.....	.....	.....
Malic acid.....	10.27	6.42	— 3.85	10.49	10.67	+ .18	10.33	7.59	— 2.74	.....	.....	.....
Protein ²	11.37	5.64	— 5.73	3.87	3.81	— .06	9.31	4.75	— 4.56	.....	.....	.....
Nicotine.....	4.60	3.80	— .80	.51	.50	— .01	3.48	3.10	— .38	2.58	.34	— .04
Nitric acid (N ₂ O ₆).....	.12	.07	— .05	1.04	1.06	+ .02	.37	.28	— .09	12.42	9.84	2.58
Ammonia.....	0	.14	+ .14	0	.03	+ .03	0	.12	+ .12	.....	.....	.....
Amid and amido com- pounds ³	3.22	5.13	+ 1.91	1.12	3.95	+ 2.83	2.64	4.84	+ 2.20	1.92	1.40	+ 1.40
Total determined ⁴ ...	76.18	58.95	—17.16	73.54	75.35	+ 1.81	75.51	63.17	—12.30	.....	4.86	+ 3.44

A.—Leaves cured by the priming method.

Constituents.	Halladay, 1910.										John Williams broadleaf; 1911-A (artificial heat applied).									
	Leaf web.			Stems.			Whole leaf.			Gain or loss.	Leaf web.			Stems.			Whole leaf.			Gain or loss.
	Green.	Cured.	Gain or loss.	Green.	Cured.	Gain or loss.	Green.	Cured.	Gain or loss.		Green.	Cured.	Gain or loss.	Green.	Cured.	Gain or loss.	Green.	Cured.	Gain or loss.	
Pure ash.....	13.03	14.04	+ 1.01	19.15	18.31	- 0.84	14.82	15.28	+ 0.46		12.16	13.29	+ 1.13	20.72	18.33	- 2.39	14.06	14.40	+ 0.34	
Starch ¹	7.53	4.54	- 2.99	7.76	6.20	- 1.56	7.60	5.02	- 2.58		7.54	4.38	- 3.16	9.41	6.71	- 2.70	7.95	4.80	- 3.16	
Sugars.....	1.97	0	- 1.97	10.88	0	- 10.88	4.57	0	- 4.57		1.64	.24	- 1.40	8.40	.04	- 8.36	3.14	.20	- 2.94	
Pentosans.....											4.72	4.74	+ .02	8.45	7.18	- 1.27	5.55	5.20	- .35	
Cellulose (crude fiber).....											7.82	7.94	+ .12	13.87	12.99	- .88	9.16	9.06	- .10	
Citric acid.....											2.19	2.48	+ .29	1.15	.99	- .16	1.96	2.15	+ .19	
Oxalic acid.....											8.52	12.28	+ 3.76	2.32	3.40	+ 1.08	7.14	10.30	+ 3.16	
Malic acid.....											6.89	4.59	- 2.30	5.87	2.91	- 2.96	6.66	4.21	- 2.45	
Protein ²	21.20	9.95	- 11.35	4.50	4.42	- .08	16.38	8.32	- 8.06		22.56	8.71	- 13.85	4.63	3.72	- .91	18.56	7.60	- 10.96	
Nitric acid (N ₂ O ₅).....	1.77	1.58	- .19	.17	.18	+ .01	1.30	1.99	- .31		3.29	3.04	- .25	.58	.59	+ .01	2.69	2.50	- .19	
Nicotine.....											1.07	1.37	+ .30	8.62	7.10	- 1.52	2.75	2.54	- .21	
Ammonia.....											.07	.40	+ .33	.05	.24	+ .19	.07	.36	+ .29	
Amid and amido compounds ³											3.60	11.12	+ 7.52	0	2.42	+ 2.42	2.80	9.18	+ 6.38	
Total determined ⁴											77.35	69.84	- 7.49	75.62	59.44	- 16.18	76.96	67.30	- 9.66	

¹ Total carbohydrates hydrolyzed by dilute acid.² Protein nitrogen $\times$ 6.25.³ Residual nitrogen $\times$ 4.8. See Table III, footnote 3.⁴ Pentosans not included.

B.—Leaves cured on the stalk.

Constituents.	Halladay, 1909.						Halladay, 1910.					
	Leaf web.			Stems.			Whole leaf.			Leaf web.		
	Green.	Cured.	Gain or loss.	Green.	Cured.	Gain or loss.	Green.	Cured.	Gain or loss.	Green.	Cured.	Gain or loss.
Pure ash.....	12.32	11.73	— 0.59	19.18	15.89	— 3.29	14.36	12.98	— 1.38	12.98	12.54	— 0.54
Starch ¹	8.22	5.27	— 2.95	12.41	6.57	— 5.84	9.47	5.71	— 3.76	6.14	4.85	— 1.29
Sugars.....	1.89	.44	— 1.45	9.77	.17	— 9.60	4.24	.36	— 3.88	1.02	0	— 1.02
Pentosans.....	4.61	4.58	— .03	8.54	6.21	— 2.33	5.78	5.12	— .66			
Cellulose (crude fiber).....												
Oxalic acid.....												
Citric acid.....												
Malic acid.....	22.44	11.15	— 11.29	4.63	2.99	— 1.64	17.06	8.77	— 8.29	20.00	8.13	— 11.87
Protein ²	2.17	1.60	— .57	.45	.31	— .14	1.66	1.21	— .45	1.53	1.46	— .07
Nicotine.....	1.75	1.81	+ .06	9.92	7.19	— 2.73	4.18	3.44	— .78	1.11	1.66	+ .45
Nitric acid (N ₂ O ₆).....												
Ammonia.....												
Amid and amido compounds ³	2.35	.73	— 1.62	0	0	0	1.65	.52	— 1.13	7.25	5.94	— 1.31
Total determined ⁴												

¹ Total carbohydrates hydrolyzed by dilute acid.² Protein nitrogen $\times 6.25$.³ Residual nitrogen $\times 4.8$. See Table III, footnote 3.⁴ Pentosans not included.

TABLE V.—Percentage of gain or loss of the nitrogenous constituents which takes place in air curing tobacco.

[Calculated from the results shown in Tables I and III.]

A.—LEAVES CURED BY THE PRIMING METHOD.

Material.	(a) Total nitrogen.			(b) Protein nitrogen.			(c) Nicotine nitrogen.		
	Leafweb.	Stem.	Whole leaf.	Leafweb.	Stem.	Whole leaf.	Leafweb.	Stem.	Whole leaf.
1908 tobacco—Havana Seed:									
Green material.....	3.32	1.22	2.75	1.82	0.62	1.49	0.80	0.09	0.61
Cured material.....	2.77	1.83	2.34	.90	.60	.76	.66	.09	.47
Gain or loss in curing {actual.....	-.55	+.61	-.41	-.92	-.02	-.73	-.14	0	-.14
Percentage of total.....	-16.7	+50	-14.9	-50.6	.....	-48.7	-17.5	0	-23
1909 tobacco—Halladay:									
Green material.....	4.05	3.66	3.95	2.57	.68	2.08	.44	.06	.35
Cured material.....	3.64	3.65	3.64	1.45	.67	1.26	.40	.07	.32
Gain or loss in curing {actual.....	-.41	-.01	-.31	-1.12	-.01	-.82	-.04	+.01	-.03
Percentage of total.....	-10.1	.....	-7.5	-43.5	.....	-39.4	.....	.....	.....
1910 tobacco—Halladay:									
Green material.....	4.61	2.89	4.11	3.40	.72	2.62	.31	.03	.22
Cured material.....	4.23	3.09	3.90	1.60	.70	1.36	.28	.03	.21
Gain or loss in curing {actual.....	-.38	+.20	-.21	-1.80	-.02	-1.26	-.03	0	-.01
Percentage of total.....	-8.3	+.6.9	-5.1	-52.9	.....	-48.1	.....	.....	.....
1911 A tobacco—John Williams broadleaf:									
Green material.....	5.27	3.03	4.77	3.61	.74	2.97	.57	.10	.46
Cured material.....	4.91	3.24	4.58	1.40	.60	1.25	.53	.11	.45
Gain or loss in curing {actual.....	-.36	+.21	-.19	-2.21	-.14	-1.72	-.04	+.01	-.01
Percentage of total.....	-6.8	+.6.9	-4	-60.9	-19	-57.8	.....	.....	.....
1911 B tobacco—John Williams broadleaf:									
Green material.....	5.18	2.84	4.66	3.39	.70	2.80	.64	.12	.53
Cured material.....	4.60	2.60	4.20	1.30	.59	1.16	.53	.12	.43
Gain or loss in curing {actual.....	-.58	-.24	-.46	-2.09	-.11	-1.64	-.11	0	-.08
Percentage of total.....	-11.2	-8.5	-9.8	-61.6	-15.9	-58.8	-17.2	0	-15.1

Material.	(d) Nitrate nitrogen.			(e) Ammonia nitrogen.			(f) Sum of protein, nicotine, nitrate, and ammonia nitrogen. (b+c+d+e.)			(g) Amid and amido nitrogen. (a-f.)		
	Leaf web.	Stem.	Whole leaf.	Leaf web.	Stem.	Whole leaf.	Leaf web.	Stem.	Whole leaf.	Leaf web.	Stem.	Whole leaf.
1908 tobacco—Havana Seed:												
Green material.....	0.03	0.27	0.10	0.04	0	0.03	2.69	0.96	2.23	0.63	0.26	0.52
Cured material.....	.02	.27	.10	.12	.02	.09	1.70	.98	1.42	1.07	.85	.92
Gain or loss in curing (percentage of total).....	— .01	0	0	+ .08	+ .02	+ .06	— .99	+ 2.1	— .81	+ .44	+ .59	+ .40
1909 tobacco—Halladay:												
Green material.....	.64	3.22	1.31	.....	.....	.....	3.65	3.96	3.74	.40	— 1.30	.21
Cured material.....	.53	2.62	1.04	.....	.....	.....	2.38	3.36	2.62	1.26	.29	1.02
Gain or loss in curing (percentage of total).....	— .11	— .60	— .27	.....	.....	.....	— 1.27	— .60	— 1.12	+ .86	— .81	+ .386
1911 A tobacco—John Williams broadleaf:												
Green material.....	.28	2.24	.72	.06	.04	.05	4.52	3.12	4.20	.75	— 1.09	.57
Cured material.....	.35	1.84	.63	.33	.20	.30	2.61	2.75	2.64	2.30	.49	1.99
Gain or loss in curing (percentage of total).....	+ .07	— .40	— .09	+ .27	+ .16	+ .25	— 1.91	— .37	— 1.56	+ 1.55	.....	1.42
1911 B tobacco—John Williams broadleaf:												
Green material.....	.23	2.08	.64	.02	.03	.02	4.28	2.93	3.99	.90	— 1.09	.67
Cured material.....	.36	1.53	.60	.45	.16	.39	2.64	2.45	2.60	1.96	.15	1.60
Gain or loss in curing (percentage of total).....	+ .13	— .50	— .04	+ .43	+ .13	+ .37	— 1.64	— .48	— 1.39	+ 1.06	.....	.93
Gain or loss in curing (percentage of total).....	+ 56.9	— 24.0	.....	+ 2,150	+ 433	+ 1,850	— 38.3	— 16.4	— 34.7	+ 118	.....	+ 133

1 See Table III, footnote 3.

TABLE V.—Percentage of gain or loss of the nitrogenous constituents which takes place in air curing tobacco—Continued.
B.—LEAVES CURED ON THE STALK.

Material.	(a) Total nitrogen.				(b) Protein nitrogen.				(c) Nicotine nitrogen.							
	Leaf web.	Stem.	Whole leaf.		Leaf web.	Stem.	Whole leaf.		Leaf web.	Stem.	Whole leaf.					
1908 tobacco—Havana Seed:																
Green material.....	3.61	1.51	3.03		2.10	0.62	1.69		0.71	0.15	0.55					
Cured material.....	2.01	1.18	1.76		.83	.49	.72		.70	.08	.51					
Gain or loss in curing (actual).....	-1.60	-1.33	-1.27		-1.27	-.13	-.97		-.01	-.07	-.04					
percentage of total.....	-41.4	-21.8	-41.9		-60.5	-20.9	-57.4			-46.6						
1909 tobacco—Halladay:																
Green material.....	4.91	3.03	4.34		3.59	.74	2.73		.38	.08	.29					
Cured material.....	2.69	2.43	2.61		1.78	.49	1.39		.28	.06	.21					
Gain or loss in curing (actual).....	-2.22	-.60	-1.73		-1.81	-.25	-1.34		-.10	-.02	-.08					
percentage of total.....	-45.3	-19.8	-40		-50.4	-33.8	-49.1		-26.3		-27.6					
1910 tobacco—Halladay:																
Green material.....	5.26	3.21	4.66		3.20	.71	2.47		.26	.04	.20					
Cured material.....	3.30	2.33	3.04		1.30	.49	1.08		.23	.02	.17					
Gain or loss in curing (actual).....	-1.96	-.88	-1.62		-1.85	-.22	-1.39		-.03	-.02	-.03					
percentage of total.....	-37.0	-27.4	-31.8		-58.0	-30.9	-52.6									
Material.	(d) Nitrate nitrogen.				(e) Ammonia nitrogen.				(f) Sum of protein, nicotine, nitrate, and ammonia nitrogen. (b+c+d+e).				(g) Amid and amido nitrogen. (a-f).			
	Leaf web.	Stem.	Whole leaf.		Leaf web.	Stem.	Whole leaf.		Leaf web.	Stem.	Whole leaf.		Leaf web.	Stem.	Whole leaf.	
1908 tobacco—Havana Seed:																
Green material.....	0.03	0.41	0.13		0.05	0	0.04		2.89	1.18	2.41		0.72	0.33	0.62	
Cured material.....	.02	.34	.12		.05	.02	.04		1.60	.93	1.39		.31	.25	.37	
Gain or loss in curing (actual).....	-.01	-.07	-.01		0	+.02	0		-1.29	-.25	-1.02		-.31	-.08	-.25	
percentage of total.....		-17.0			0		0		-41.5	-21.2	-42.3		-.43	-24.2	-30.3	
1909 tobacco—Halladay:																
Green material.....	.45	2.57	1.08						4.42	3.39	4.10		.49	1.36	.24	
Cured material.....	.52	1.87	.93						2.58	2.42	2.53		.11	.01	.08	
Gain or loss in curing (actual).....	+.07	-.70	-.15						-1.84	-.97	-1.57		-.38	-.95	-.16	
percentage of total.....	+.15.5	-27.3	-13.9						-41.6	-28.5	-38.3		-77.5	-.97	-66.7	
1910 tobacco—Halladay:																
Green material.....	.29	2.85	1.04						3.75	3.60	3.61		1.51	1.39	1.05	
Cured material.....	.43	2.03	.87						1.96	2.54	2.12		1.34	.21	.92	
Gain or loss in curing (actual).....	+.14	-.82	-.17						-1.79	1.06	1.49		-.17	-.21	-.13	
percentage of total.....	+.48.2	-28.8	-16.3						-47.8	-32.2	-41.3		-11.2		-12.4	

¹ See Table III, footnote 3.

In the experiments with picked leaves any apparent differences in the ash content of the whole leaf as between the green and cured leaves are, of course, due to slight differences in the composition of the duplicate samples and to experimental errors. As between the two leaf parts, however, it is to be observed that in every instance the leaf web appears to gain in ash content at the expense of the midrib during the curing. There is no doubt that this movement of mineral matter from stem to web takes place during the later stages of drying, and tobacco growers are familiar with the discoloration frequently caused thereby in the leaf in the vicinity of the stem. The movement is doubtless due simply to diffusion and is not to be connected with the reverse movement due to physiological translocation. As is well known, the leaf web normally dies and dries long before the stem, and the latter finally collapses rather suddenly. The remaining cell sap then oozes out into the leaf web, causing the discoloration referred to. This movement of materials, occurring after the death of the protoplasm, is not large and is localized. In the experiments in stalk curing there is a loss of ash in curing in the leaf as a whole, which, of course, can not be due to respiration and can only be accounted for by the assumption that a portion of the ash has passed into the stalk.

CHANGES IN THE CARBOHYDRATES.

In both methods of curing, nearly all the starch disappears both from the leaf web and from the midrib during the process. We have been unable to obtain a reaction for starch by the iodine test in the cured samples. This is in accordance with the results of Müller-Thurgau already referred to. The more or less complete disappearance of starch is one of the most characteristic changes involved in curing, and the relative freedom from starch of the cured leaf is a measure of the completeness of the curing process. It will be seen also that in complete curing by either method practically all of the reducing sugars disappear. The incompletely cured samples of 1908 reveal the fact, however, that the disappearance of starch precedes that of the sugars, as is to be expected, and, furthermore, that there is a temporary accumulation of sugars in the midrib, undoubtedly derived from the starch of the leaf web. It has been pointed out that analyses of flue-cured leaf have shown that under that system of rapid curing the leaf contains high percentages of reducing sugars, which are doubtless derived from the splitting up of starch, and the premature killing of the protoplasm prevents the oxidation of the sugars by respiration.

Our results as a whole indicate that the pentosans, which, generally speaking, are not physiologically plastic, undergo but little change in the leaf web, but in the stems there is a more decided decrease of these constituents. The crude-fiber content undergoes little or no change, except that in complete curing there appears to be a slight

decrease in the stems, no doubt due to loss of pentosans or related hemicelluloses rather than to any change in true cellulose.

CHANGES IN THE NONVOLATILE ORGANIC ACIDS.

Tobacco leaves contain considerable quantities of oxalic, malic, and citric acids, and the changes which these undergo during the curing are interesting from the physiological point of view. That these acids are of importance in plant metabolism is generally recognized, but their rôle has not been fully determined. Because of their close relationship to the amido acids, such as aspartic acid and asparagin, it seems reasonable to associate them with protein synthesis. It is generally believed, however, that oxalic, citric, and malic acids have their origin in the incomplete oxidation of sugars when respiration proceeds in the presence of a limited oxygen supply. It appears that under certain conditions these acids may be converted partially into sugars, on the one hand, and partially into carbon dioxid and water, on the other hand. So far as we know, no distinction has been made heretofore as to the metabolic transformations which these three different acids undergo in the plant, but our results with green and cured tobacco leaves show that they behave quite differently during the curing process, which involves essentially the phenomena of respiration and of translocation.

It is evident that the content of oxalic acid is not changed during the curing, and this is equally true in both methods of curing. There is a decided loss of malic acid during the curing when the leaf is primed, as well as when it is cured on the stalk. Citric acid, on the other hand, undergoes no decrease during the curing by either method, and, indeed, there is a considerable increase in content of the acid, which is surprising in view of the behavior of the malic acid. It is, of course, conceivable that the malic acid is partially transformed into citric acid, but a simpler view is that the citric acid resists oxidation to lower products more than the malic acid, so that during the process of partial oxidation of the sugars to acids there is a gradual accumulation of citric acid, while the malic acid is more completely oxidized to water and carbon dioxid.

CHANGES IN THE NITROGENOUS CONSTITUENTS.

Referring to Tables IV and V, it will be seen that the loss in protein in curing is very large in all cases, in some instances exceeding 60 per cent of the total. The marked decrease in protein content, like the disappearance of starch, is a characteristic change involved in curing, and the relative decrease is an index of the completeness of the curing.

The decrease in starch content and in protein content furnishes a simple and reliable means of determining by chemical analysis the progress and the completeness of barn curing.

There is undoubtedly a considerable loss in nicotine content in curing due to simple volatilization, but all this loss is not shown in our experiments, for the reason that the green or uncured, as well as the cured, leaves were dried at about 80° C. and this temperature is sufficient to expel the more readily volatile portion of the nicotine.¹ In the leaf as a whole there appears to be no marked change in the content of nitric acid in either method of curing. The indicated loss of nitrate in the stem is probably only apparent, at least in part, since about the same losses are indicated for curing the primed leaves as for curing on the stalk. The determinations of nitrate were based on the well-known method of reduction with ferrous chlorid in acid solution and measurement of the oxid of nitrogen liberated. In all cases, however, it was found that with the green stems a sharp end reaction could not be obtained, for, after the principal reaction was completed, a slow evolution of gas continued almost indefinitely, apparently due to some reaction other than the reduction of the nitrate. The values for nitric acid in the green stems are therefore somewhat too high, which would, of course, have the effect of indicating a loss of nitric acid in curing. That the results for the green stems are too high is further indicated by the fact that the sum of the protein, nicotine, and nitrate nitrogen as obtained somewhat exceeds the total nitrogen in the green stems.

In the primed leaves there is a very marked increase in the amid and amido compounds, corresponding to the large decrease in protein. A considerable portion of these cleavage products of protein pass from the leaf web into the stem, which in the green condition contains practically none of these products. In the case of stalk-cured leaves there is no increase in amid and amido products, but, on the contrary, a considerable decrease, although the decrease in protein in this method of curing is even greater than in curing the primed leaves. Evidently the phenomenon of translocation is here an important factor. In the leaves cured by priming there is always a considerable loss of total nitrogen, which can not be due to translocation, and since there is no equivalent loss of nicotine the nitrogen doubtless escapes in the form of ammonia. The odor of ammonia is readily recognized in the curing barns, and there can be no doubt that it is liberated during the curing process. In other words, the cleavage products of protein are further changed, with ammonia as one of the decomposition products. The observed increase in content of ammonia, therefore, represents only a portion of the total quantity formed during the curing, the amount which becomes fixed in the leaf doubtless depending on the quantity of free acid present.

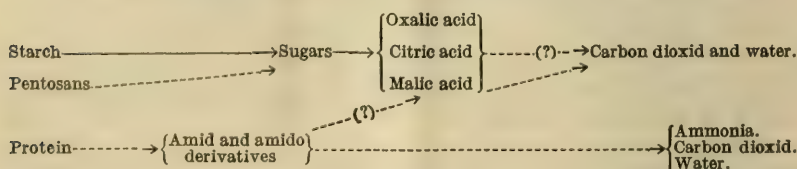
¹ Garner, W. W. Relation of nicotine to the quality of tobacco. U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 141, p. 5-16, 1909.

Considering collectively the changes in the various constituents involved in curing, we find in the case of the primed leaves that, where the analyses are complete, the sum of the various losses recorded, less the sum of the gains, gives a total loss amounting to from 70 to 90 per cent of that obtained in Table I; or, in other words, our analyses have accounted for this proportion of the constituents which are of importance from a quantitative standpoint. A very close agreement is not to be expected, since the factors used in calculating the protein and the amid and amido constituents are probably only approximately correct. The results of the analyses account for about 75 per cent of the loss in weight indicated in Table I, where the leaves are cured on the stalk.

Aside from the observations made by Müller-Thurgau regarding the loss of starch and sugars in the curing, which have already been mentioned, the only paper bearing directly on the changes in composition during the curing, so far as known, is that of Behrens,¹ who, like nearly all previous investigators, was concerned mainly in a comparison of the methods of curing on the stalk and of curing the primed leaves. He presents data, however, showing the comparative composition of green and cured leaves. Since the total loss of weight in curing was not determined, the changes in composition can only be considered qualitatively. His analyses indicate the disappearance of starch and a decrease in sugars and protein nitrogen in curing. They show also a relative loss of total carbon and a relative gain in total nitrogen during the curing process.

While little is known as to the identity of the individual compounds making up the groups of constituents involved in the curing changes, particularly as regards the protein group and their cleavage products, the general character and course of the transformations concerned can be considered as definitely established. The following scheme shows the general course of the changes common to both methods of curing which the several groups of constituents undergo during the curing process, the prime factor in effecting these transformations being respiration, although the phenomena of translocation play a more or less important rôle, depending on the method of curing followed.

Diagram showing the general course of changes during the curing process.



¹ Behrens, Johannes. Weitere Beiträge zur Kenntnis der Tabakpflanze. Die Landwirtschaftlichen Versuchs-Stationen, Bd. 43, p. 271-301, 18

In the above scheme the changes which take place quantitatively are indicated by solid lines, and partial transformations are indicated by broken lines. The transformation of the sugars into nonvolatile organic acids is bracketed, for the reason that, although the sugars are quantitatively removed, it is not known to what extent the acids are formed as intermediate products of oxidation. There is some question as to whether citric acid is further oxidized during the curing process, and it has not been actually proved that nitrogen-free acids are formed by the hydrolysis of the amido derivatives of protein, although this seems highly probable. The scheme merely presents the course of events in the breaking up of the surplus food supply in support of respiration, and does not take into account the movements of the soluble products due to physiological translocation.

It will be seen that the so-called ether extract, which is usually included in the analysis of agricultural products and which is intended to show the content of fat or oil, has not been considered in connection with our studies on the changes in composition taking place during the curing. It has not been considered that this determination would throw any light on the problems in hand, for the extract obtained from tobacco leaves is a hopelessly complex mixture, containing a portion of the nicotine, chlorophyll, and its decomposition products, tobacco resins, etc., and in reality containing at most very small quantities of constituents which could be properly called fat or oil. No methods are at present available for the quantitative separation of the several constituents of the ether extract, and it is obvious that the crude extract would contain several constituents already accounted for in the analyses.

The results which have been presented and discussed in the preceding paragraphs apply more particularly to typical air curing. Samples A and B of 1911, in Tables IV and V, should bring out any differences in the final result of the curing when air curing is modified by the moderate use of artificial heat. As a matter of fact these duplicate samples, after curing, show almost exactly the same composition; so that, although the moderate application of heat hastens the rate of curing, as shown by the appearance of the tobacco during the progress of the process, the final result, so far as shown by the analyses, is the same, whether or not the heat be applied. In the case of flue curing, where much higher temperatures are used, no comprehensive investigations have been made; but analyses of the cured leaves which have been reported show that the curing changes are of the same character as in air curing, the only difference being that in flue curing the transformations are less complete. In typical fire curing, in which the tobacco is only partially cured by the use of heat, the relative completeness of the chemical changes involved probably falls between that in air curing and that in flue curing.

CURING THE LEAVES ON THE STALK COMPARED WITH CURING THE PICKED LEAVES.

The relative merits of the two methods of curing have long been a subject of interest to agricultural investigators, both in this and in foreign countries, and the greater portion of the experimental work relating to tobacco curing which has been done has had special reference to this problem. Some of the earlier investigators maintained that the leaf weighed more when cured on the stalk, because of a flow of soluble material from the stalk into the leaf. Others, however, notably Nessler¹ and Behrens,² maintained that there was no particular difference in results as between the two methods of harvesting and curing, either with reference to weight or to quality of the cured leaf. We are indebted to Mohr³ for the first comprehensive and decisive study of the subject. Mohr brought out clearly the errors in the methods of procedure and in the interpretation of results made by previous investigators and proved beyond doubt that for the particular type of tobacco with which he worked (cigar-wrapper leaf) the leaf cured on the stalk loses in weight approximately 11 or 12 per cent more than if cured after being picked from the stalk. This is equivalent to saying that a picked leaf after curing will weigh 11 or 12 per cent more than would the same leaf if cured on the stalk. Mohr proved conclusively by analyses of the ash and other constituents that the increased loss in weight which occurs when the leaf is cured on the stalk is due not so much to a more intense respiration but rather to a translocation of nutritive material from the leaf into the stalk.

Coming to our own experiments, by reference to Table I (p. 5) it is seen that with comparable material harvested and cured by the two methods in question during the years 1908, 1909, and 1910 the losses in dry weight by curing the leaves on the stalk were 12.2, 18.9, and 10 per cent, respectively, greater than the losses in curing the picked leaves. The larger indicated difference in loss of weight between the two methods for 1909 is to a great extent due to the unusually small loss in weight of the picked leaves, and this in turn is fully explained by the abnormally low content of starch of the picked leaves at the time of harvesting. However, the average difference between the losses in weight for the three years by the two methods of harvesting and curing is 13.7 per cent, taking the figures as they stand; and this value is in close agreement with Mohr's results for the same general type of tobacco, namely, cigar-wrapper leaf. On the other hand, Table II (p. 8) shows that the difference in loss

¹ Nessler, J. *Der Tabak, seine Bestandtheile und seine Behandlung*, Mannheim, 1867.

² Behrens, Johannes. *Weitere Beiträge zur Kenntnis der Tabakpflanze*. Die Landwirtschaftlichen Versuchs-Stationen, Bd. 43, p. 280, 1894.

³ Mohr, E. C. J. *Gepflückter und am Stamme getrockneter Tabak*. Die Landwirtschaftlichen Versuchs-Stationen, Bd. 59, Heft 3/4, p. 253-292, 1903.

of weight in curing between leaves harvested on the stalk and those picked from the stalk may be much greater with some of our manufacturing and export types, which are grown under different conditions and harvested in a much riper state than the cigar-wrapper types. It will be seen that in stalk curing there was a loss of about 9 to 10 per cent of the original content of pure ash, which is in close agreement with Mohr's results. In curing the primed leaves there can, of course, be no loss of ash. Our results show that, although the cured picked leaves contain little or no starch, the removal of insoluble carbohydrates is pushed considerably farther when the leaves are cured on the stalk. There is a more marked decrease of pentosans in stalk curing. There is no essential difference in the results as between the two methods with reference to sugar content, since in both cases there is a practically entire disappearance of sugars when the curing is complete.

The compounds of nitrogen are decidedly the most important constituents of the leaf in regard to differences in the results of curing on the stalk as compared with curing the picked leaves. For the three years for which direct comparisons are made, the loss in protein nitrogen in the leaf web, and particularly in the midrib, was decidedly greater in stalk curing than in curing the picked leaves. Since the temperature employed in drying the samples was sufficient to expel the easily volatilized portion of the nicotine, no definite conclusion can be drawn as to the differences in loss of this constituent in the two methods of harvesting. The results regarding nitrate nitrogen are unsatisfactory, doubtless because of the difficulty in obtaining reliable results with the uncured material, as pointed out on page 28. As a whole, the results do not indicate a very marked translocation of nitrates into the stalk. As far as they were carried, our results indicate that ammonia is readily translocated into the stalk.

In comparing the results of the two methods of curing with reference to changes of composition, the most striking difference is to be found in the behavior of the nitrogenous cleavage products from the hydrolysis of protein. From 40 to 60 per cent of the protein is broken up during the curing process and, although the loss in total nitrogen in curing the picked leaves shows conclusively that a portion of the nitrogen of the decomposition products escapes as ammonia, the loss thus involved is but a comparatively small portion of the whole. The result is that there is a marked accumulation of amid and amido compounds in the cured picked leaves, the increase in this form of nitrogen amounting to 0.5 to 1.5 per cent of the leaf weight, or 100 to 400 per cent more than was contained in the uncured leaf. In the stalk-cured leaves, on the other hand, not only are the products resulting from the splitting of the protein completely removed, but a considerable portion of the amid and amido com-

pounds originally present in the leaf are also removed in the process of curing. In stalk curing, the loss of nitrogen in these forms amounts to 35 to 45 per cent of the total protein and amid and amido nitrogen, while in curing the picked leaves the direct loss of nitrogen in these forms by the splitting off and escape of ammonia averages less than 10 per cent of the total. In stalk curing, the content of amid and amido nitrogen alone is reduced by about 15 to 60 per cent, depending on the original content of these forms of nitrogen. As regards total nitrogen, the loss in curing the picked leaves is from 4 to 15 per cent of the total, while the loss in stalk curing is from 35 to 42 per cent.

As regards the organic acids, there is no decided difference in the behavior of oxalic acid in the two methods of curing, and this is true also as to malic acid. Citric acid seems to accumulate to approximately the same extent whether the leaf is attached to the stalk or is detached during the curing. There is no satisfactory evidence that these acids undergo translocation in stalk curing.

Summing up the more important differences in the results of curing the leaves on the stalk as compared with curing the picked leaves which are brought out in our experiments, it is seen that the loss in weight of dry matter is 10 to 15 per cent greater when the leaves are cured on the stalk. This difference is due mainly to the more complete removal of carbohydrates, including the pentosans, and of protein and, more particularly, to the translocation of the cleavage products of protein and of the mineral constituents from the leaf into the stalk. In stalk curing, in addition to the respiration activities which constitute the important factor in curing the picked leaves, the translocation of mobile materials from the leaf into the stalk assumes an important rôle. This translocation of materials from leaf to stalk in stalk curing constitutes, in fact, the essential difference between this method of curing and that in use after the leaves are removed from the stalk. Our results on this phase of tobacco curing agree closely with the conclusions reached by Mohr from his study of the subject. These results find additional support in the work of Johnson¹ relating to the composition of two lots of tobacco stalks, from one of which the leaves were removed at the time of harvesting, while the second lot was allowed to cure with the leaves attached. The analyses of the two lots of stalks show that those which were allowed to cure with the leaves attached gained approximately 30 per cent of their original content of total nitrogen, 36 per cent of their content of phosphoric acid, and 8 per cent of their content of potash. This gain in nitrogen, phosphoric acid, and potash can only be accounted for on the assumption that

¹ Johnson, S. W. Analyses of tobacco stalks when cut and after curing. Connecticut Agricultural Experiment Station, 16th Annual Report, 1892, p. 31-34. 1893.

these constituents were transported from the leaf into the stalk during the process of curing. It is evident that the phenomena of translocation in the curing of tobacco leaves attached to the stalk follow essentially the same laws as obtain during the growth and development of plants under normal conditions. The movement of reserve nutrients is from the leaf web through the veins and midrib into the stalk and normally thence to the younger growing parts. Only such constituents as are the most essential, physiologically, undergo translocation to a marked degree.

ENZYMS IN TOBACCO CURING.

It has been pointed out in the preceding pages that tobacco curing consists, primarily, in the hydrolysis of insoluble carbohydrates and proteins, followed by a partial or complete removal of the cleavage products by further hydrolysis and by oxidation and, in stalk curing, by translocation into the stalk. It is quite generally recognized that the immediate agencies effecting transformations of this character in the vital activities of the plant are enzymes. We have shown that starch and pentosans are converted into reducing sugars, which are then oxidized or translocated, and that protein is converted into the simpler amid or amido derivatives, from which, in turn, ammonia is split off. It seems probable, therefore, that diastases, cytases, and proteolytic and deamidizing enzymes take part in the curing of the tobacco leaf. It seems very probable also that the oxidases play an important part, particularly as regards the changes in color which the leaf undergoes in curing.

We have not attempted to go into a study of the enzymes concerned in tobacco curing, except simply to bring out the fact that their activities are for the most part intimately associated with and dependent upon the presence of the living protoplasm. We have already pointed out that a ripe tobacco leaf will not cure properly, even under the most favorable conditions, if it has been previously subjected to very high or low temperatures or to the action of protoplasmic poisons. It has also been stated that the progress of the curing can be readily followed by determining at different stages the relative quantities of unchanged starch and protein contained in the leaf. The following experiments show by chemical methods that the premature killing of the protoplasm prevents the changes in composition which are essential to successful curing.

In the first place, an experiment was carried out to determine the effectiveness of rapid drying at high temperatures in preventing these changes in composition. Two lots of leaves, containing 14 leaves in each lot, were selected in the manner described on page 4, and one of these lots was allowed to cure normally. The midribs were re-

moved from the second lot of leaves and the half of each leaf thus resulting was plunged into boiling absolute alcohol for a few minutes, while the second set of leaf halves was immediately placed in an air bath heated to 90° C. and dried. The results of the experiment are shown in Table VI. In the case of material killed with alcohol the results were corrected, of course, for the matter extracted by the alcohol. To facilitate comparison, the results are presented on a uniform basis of 14 whole leaves, exclusive of the midribs.

TABLE VI.—*Effectiveness of killing fresh tobacco leaves at high temperatures, as compared with killing with hot alcohol in arresting changes in composition.*

1911 material.	(a) Leaf web killed with alcohol.	(b) Leaf web killed at high tem- perature.	(c) Leaf cured normally.
Dry weight of 14 leaves.....grams.....	126.2	124.6	97.5
Loss of weight in curing.....per cent.....		1.3	22.8
Starch.....do.....	26.64	24.57	5.17
Protein nitrogen.....do.....	2.04	2.13	1.22
Reducing sugars.....do.....	1.21	1.63	3.86

In the above table the results are calculated on a basis of the original dry weight of the leaves, as represented by *a*. These results show that, while subjecting the leaf to a temperature of 90° C. does not immediately stop all action upon the carbohydrates, this method, which was employed in all the experiments already described, answers satisfactorily for the purposes in view. Having established this point, the effect on the curing process of chloroforming the leaf was next studied. A lot of five ripe leaves was collected and their midribs removed. The one lot of leaf halves thus obtained was immediately dried at 90° C., as in the preceding experiment, while the second lot was exposed to chloroform vapors in a closed jar for a few minutes and then placed under the proper conditions for normal curing. After four days this material was also dried at 90° C. The results of the experiment are shown in Table VII.

TABLE VII.—*Effect of exposure to chloroform on the curing of tobacco leaves.*

1912 material.	Leaf dried at 90° C.	Leaf chlo- roformed and then "cured."
Dry weight of 5 half leaves.....grams.....	18.7	19.00
Starch.....per cent.....	41.74	43.88
Protein nitrogen.....do.....	1.17	1.23

It is obvious that exposure to chloroform effectually prevents those changes in composition which are characteristic of normal curing and, indeed, the appearance and properties of leaves so

treated clearly show that normal curing does not take place. Since these normal changes in composition are effected by hydrolytic enzymes, and since it is well known that the green leaves of plants normally contain these enzymes, it is not clear why protoplasmic poisons which do not inhibit the action of such enzymes should prevent the progress of the curing along these lines. Brown and Morris¹ considered this matter in connection with their investigations on the occurrence of diastase in the leaves of plants, but did not arrive at a satisfactory conclusion. They found that, although the diastatic activity of the leaf increases markedly when it is kept in darkness, even when a leaf has been subjected to this treatment there is no further decrease of starch after treatment with chloroform. Whatever the explanation of this phenomenon, it seems logical, as suggested by Brown and Morris, that partial starvation will lead to an increased formation by the leaf cell of enzymes designed to furnish the needed nourishment. We have found that such is the case as regards diastase in the curing of tobacco leaves. The method used for comparing the diastatic activity of fresh and partially cured leaves was that described by the above-named investigators, and consists essentially in digesting a given weight of the material with a 2 per cent water solution of soluble starch under proper conditions and with suitable controls. The increase in reducing sugars is taken as a measure of the relative diastatic activity.

In the following experiments, after having obtained the leaf areas, one half of each leaf was chloroformed and dried at 35° C., while the remaining half of each leaf was maintained under normal curing conditions (slow drying in darkness and at moderate temperatures) for a period of 43 hours in experiment 1 and for one week in experiment 2.

The material chosen for the first experiment was a single mature bottom leaf taken from a Connecticut Broadleaf plant grown in the greenhouse, and in the second experiment one bottom and two top leaves were taken from a mature plant of Yellow Pryor grown under normal field conditions. The cured material was chloroformed and dried in the same manner as the uncured. The diastatic activity was determined for equal areas and not equal weights of the cured and uncured material, and the results as reported are in terms of the weights of maltose formed by digesting 10 grams of the uncured samples chosen as standards and weights corresponding to an equal area of the other samples with 2 per cent soluble starch solution for 48 hours at 30° C. It is necessary to use equal areas of leaf to correct properly for the loss in dry weight in curing. The results of these experiments are shown in Table VIII.

¹ Brown, H. T., and Morris, G. H. Contribution to the chemistry and physiology of foliage leaves. *Journal, Chemical Society [London], Transactions*, v. 63, p. 604-659, 1893.

TABLE VIII.—*Diastatic activity of uncured and partially cured tobacco leaves.*

Material.	Total weight of material.	Weight per square foot.	Loss of weight in curing.	Weight of leaf used.	Relative diastatic activity.
Experiment 1 (14 square inches of leaf surface used):					
A bottom leaf—	<i>Grams.</i>	<i>Grams.</i>	<i>Per cent.</i>	<i>Grams.</i>	
Green half.....	6.47	5.124	-----	0.5000	4.41
Cured half.....	5.67	4.489	12.4	.4378	5.48
Experiment 2 (9.8 square inches of leaf surface used):					
2 top leaves—					
Green halves.....	7.634	7.354	-----	.5000	2.04
Cured halves.....	4.836	4.659	36.7	.3167	7.02
A bottom leaf—					
Green half.....	8.536	7.940	-----	.5398	2.48
Cured half.....	5.004	4.655	41.4	.3164	6.50

The above results show very clearly that there is a marked increase in the diastatic activity of tobacco leaves during the curing process. It seems probable that there is a similar increase in the proteolytic enzymes during the curing, but no attempt was made to determine this point.

TOBACCO CURING AS AFFECTED BY EXTERNAL CONDITIONS.

Since respiration plays a fundamental rôle in tobacco curing, it is to be expected that the external conditions, notably the temperature, will have a decided influence on the curing process. The factors of importance in this connection are the temperature and relative content of moisture, oxygen, and carbon dioxide of the surrounding atmosphere and the presence or absence of light. We have made some experiments on the relation of the first two of these factors to the rate of curing, using the quantities of starch and protein hydrolyzed as a measure of the progress of the curing.

EFFECT OF TEMPERATURE ON RATE OF CURING.

In 1911 three lots of six leaves each were collected, using the precautions already described in detail, to have the three lots strictly comparable. The stems were removed from the first lot of leaves (*a*) and the leaf web killed by plunging into boiling absolute alcohol, after which the leaf web and stems were dried at 80° C. The second lot of leaves (*b*) was placed in a bell jar and maintained at a temperature of approximately 10° C. (50° F.) for 24 hours, after which they were treated exactly like the first lot. The third lot (*c*) was similarly maintained at a temperature of approximately 24° C. (75° F.) for 24 hours and then treated like the other two lots. In 1912 the experiment was repeated with two lots of five leaves each. The stems were removed from the first lot (*a*), one half of each leaf being quickly dried at 90° C., while the remaining leaf halves were chloroformed and placed under favorable conditions for curing for a period of four

days before being dried in the oven. (This material served also for the data presented in Table VII.) The stems were also removed from the second lot of leaves (*b*) and one half of each leaf maintained in a bell jar at an average temperature of 12° C. (54° F.) for 48 hours, while the second half of each leaf was similarly treated, but at an average temperature of 27° C. (80° F.). These leaf halves were then quickly dried at 90° C. The results of these experiments are given in Table IX.

TABLE IX.—*Effect of temperature in hastening rate of curing.*

Material.	(a) Leaf killed with alco- hol (1911) or with heat (1912).	(b) Leaf par- tially cured at 10° to 12° C.	(c) Leaf par- tially cured at 24° to 27° C.
1911 samples:			
Total dry weight of 6 leaves, including stems.....grams..	61.1	61.5	57.6
Starch (leaf web).....per cent..	28.47	25.17	21.33
Protein nitrogen (leaf web).....do....	1.90	1.94	1.59
1912 samples:			
Total dry weight of 5 half leaves, without stems.....grams..	18.7	18.3	17.4
Starch.....per cent..	41.74	37	26.46
Protein nitrogen.....do....	1.17	1.03	.87

From the above table it is seen that where the leaf was allowed to cure for 24 hours there was a loss of about 3.3 per cent of the starch content at the lower temperature and of 7.1 per cent at the higher temperature, while for the leaf tissue cured for 48 hours the losses were 4.7 per cent and 15.3 per cent, respectively. There was no decrease in protein in the first case at the lower temperature, but a considerable decrease at the higher temperature; and in the second case there was only a small decrease at the lower temperature, but the decrease at the higher temperature was very marked. It is evident that the rate of curing is proportional to the temperature, which is in accord with the well-known principle that normal respiration, as measured by the rate of evolution of carbon dioxid, increases regularly with rise in temperature; and it is interesting to note that in tobacco curing the rate of increase in the speed of the reactions involved tends to obey the law of Van't Hoff that the speed of ordinary chemical reactions is approximately doubled for each increase of 10 degrees centigrade in temperature, provided, of course, that in this case the optimum temperature for the enzymes involved in curing is not much exceeded.

EFFECT OF MOISTURE ON THE RATE OF CURING.

It is well known that the rate of drying is of fundamental importance in practical tobacco curing, and when the quantity of water in the leaf has been reduced to certain limits the progress of the curing

is practically stopped. On the other hand, if too much moisture remains in the leaf toward the end of the curing, when the leaf cells are dying, abnormal processes of decay, commonly known as pole-sweat, set in, which result in the disintegration of the leaf tissue. This latter trouble is due, however, to the invasion of foreign organisms and needs no further consideration here. Aside from these extreme conditions, we have to consider the effects of partial loss of water by the leaf in the course of the curing process. It is stated by some authorities that normal respiration is most active when the cells are fully turgid; that is, in the presence of a maximum amount of water. It appears from our experiments, however, that this principle does not hold so far as it relates to tobacco curing.

In 1911 two ripe tobacco leaves were selected and the midribs removed. The two right-hand leaf halves were suspended in a tall closed jar for 24 hours over concentrated sulphuric acid on which was floated a dish containing a little caustic soda. The corresponding left-hand leaf halves were similarly placed in a jar containing only the caustic soda. The two lots of material were then killed with hot alcohol in the usual manner and prepared for analysis. The material which had stood over sulphuric acid was quite limp from loss of water, but the other sample had scarcely wilted. The leaves used in this experiment are comparable with those used for the 1911 experiment shown in Table IX and therefore originally contained approximately 28.5 per cent of starch and 1.9 per cent of protein nitrogen. A similar experiment was made in 1912 with a lot of five leaves, the corresponding halves of which were subjected to the different rates of drying for 28 hours and then quickly dried at 90° C. This material is comparable with the 1912 samples used in the experiment presented in Table IX and therefore originally contained approximately 42 per cent of starch and 1.2 per cent of protein nitrogen. The results of the tests are shown in Table X.

TABLE X.—*Effect of partial drying on rate of curing.*

Material.	Leaf partially dried.	Leaf not dried.
1911 samples:		
Total dry weight of 2 leaf halves.....grams..	8.7	8.7
Starch.....per cent..	12.61	18.27
Protein nitrogen.....do....	1.49	1.56
1912 samples:		
Total dry weight of 5 leaf halves.....grams..	19.05	19.75
Starch.....per cent..	30.76	34.55
Protein nitrogen.....do....	1.13	1.10

The final dry weight of the two 1911 samples was the same, but as there was a marked difference in starch content at the end of the experiment it is evident that the leaf halves subjected to partial drying were originally somewhat heavier than those not subjected to

drying. It is seen that initial partial drying materially hastens the disappearance of starch, but for the interval of time covered by the experiments there was no important difference in the rate of hydrolysis of protein. The less-marked differences as regards starch in the 1912 experiment were doubtless due to the fact that there was much less difference in water content (about 8 per cent) between the two samples as a result of the partial drying than was the case with the 1911 samples. In view of these results it appears that the thorough wilting of the tobacco leaves at the beginning of the curing process promotes good curing.

SUMMARY.

Curing is essentially a life process, as is shown by the fact that killing the protoplasm at excessively low or high temperatures or by means of poisons, such as chloroform, effectually prevents normal curing. It follows, also, that imperfect curing can not be fully corrected in the subsequent process of fermentation, which is not dependent on the living protoplasm.

Experiments covering a period of four years have shown that in the case of cigar-wrapper-leaf types the average loss in weight of dry matter in curing the picked leaves is 12 to 15 per cent, while in curing the leaves on the stalk the loss in dry weight is approximately twice as great. In other words, a cigar-wrapper leaf picked from the stalk will weigh after curing approximately 14 to 18 per cent more than would the same leaf when cured on the stalk.

In the curing of the export and manufacturing types and of cigar-filler types, which are harvested in a ripper or more mature condition, the loss in weight of dry matter is greater than in the case of cigar-wrapper leaf, frequently amounting to 35 to 40 per cent, even when the leaves are picked from the stalk in harvesting. With most of the export and manufacturing types the stalks are split in harvesting, and under these conditions the loss in dry matter in curing is considerably less than when the stalk is simply severed near the base in harvesting.

The chemical changes which take place in curing can only be properly brought out by presenting all results on the basis of the uncured leaf. It has been shown that in thorough air curing all starch and reducing sugars disappear and there is a decrease of pentosans and malic acid, while there is an increase in citric acid and the cellulose content remains unchanged. There is a large decrease in protein, in some cases amounting to 60 per cent of the total, and a considerable decrease in nicotine and total nitrogen. Appreciable quantities of ammonia are formed in the process.

In the curing of picked leaves the chemical changes appear to be due almost wholly to respiration, while in curing the leaves on the stalk the phenomenon of translocation from the leaf into the stalk

plays an important rôle. This translocation, which constitutes the essential physiological difference in the two methods of curing, involves the transfer into the stalk of the amid and amido compounds derived from the protein, ammonia and a portion of the mineral constituents, nitrate and, doubtless, a portion of the carbohydrates. The picked leaves after curing contain, therefore, much larger quantities of amid and amido compounds, and ammonia and somewhat larger quantities of mineral matter and nitrate than the leaves cured on the stalk.

The physiological processes characteristic of tobacco curing indicate the presence of diastatic, proteolytic, and deamidizing enzymes, and probably also of oxidases. The process of starvation to which the leaves are subjected leads to an increased secretion of diastase during the progress of the curing.

Temperature has a very marked effect on the rate of curing. The rate of curing increases very rapidly with rise in temperature up to the killing point of the protoplasm (about 130° F.). The moderate use of artificial heat in air curing does not materially affect the final result in curing so far as measured by the ordinary methods of chemical analysis, provided other conditions remain favorable in both cases.

Thorough wilting in the initial stages of the curing promotes the progress of the process, provided the further drying of the leaf is not allowed to proceed too rapidly.





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(PROFESSIONAL PAPER.)

EFFECTS OF VARYING CERTAIN COOKING CONDITIONS IN PRODUCING SODA PULP FROM ASPEN.¹

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PURPOSE OF EXPERIMENTS.

At the present time practically all of the soft, easy-bleaching pulps used for the manufacture of high-class book, magazine, general printing, and the cheaper writing papers are made by the soda process. In England such pulps are produced from esparto (alfa, or Spanish grass); in America, from the poplars and similar woods. Although the soda process of wood-pulp manufacture is not employed commercially to so great an extent in America as the sulphite and mechanical processes, it is remarkably well adapted for producing pulp fibers from any kind of wood or other fibrous vegetable material, no matter how resistant to chemical attack it may be. For this reason it is much used in the experimental work of the Forest Service.

To insure that a wood has been subjected to the most favorable cooking conditions it is necessary to cook it under many different conditions produced by varying such factors as the amount and concentration of the cooking chemical and the duration and temperature of cooking. While the general effect of using greater or less severity of cooking is well recognized in mill practice, there has been almost no available information on the quantitative effects of the individual factors concerned nor on the limitations within which such effects are exerted. Such meager information as may be found in the literature is widely scattered and is not strictly applicable to manufacturing conditions. Notwithstanding modern improvements and the general tendency toward more efficient operations in commercial plants, the most economical production apparently is not being attained by all of the soda-pulp mills. This is indicated by the fact that some of them are using from 10 to 20 per cent more pulp wood, from 50 to 100 per cent more chemicals, and from 10 to 40 per cent

¹ This paper presents detailed information of value in experimental work in the laboratory and in promoting the efficiency of commercial paper-making plants employing the soda process.

more steam, and require much larger plants and more labor for the same tonnage output per day than others making similar products. It was to secure and make available detailed information which would both facilitate other experimental work in the laboratory and promote the efficiency of commercial plants employing the soda process that the series of tests discussed in this bulletin was undertaken. They were carried out at the Forest Products Laboratory maintained by the Forest Service at Madison, Wis., in cooperation with the University of Wisconsin.

The report of the experimental work is prefaced by a short description of the soda process and a review of previous investigations. Some general comments on aspen as a raw material for soda pulp and on the pulp itself will be found in the appendix, pages 41-47. This species of poplar was selected as the test material because it is the most important soda pulpwood. The information secured, however, is of much value also in connection with the cooking of other woods.

THE SODA PROCESS AND ITS APPLICATION.

What is here referred to as the soda process may be considered as a modification of the old Watt and Burgess process, first practiced in 1853,¹ and probably the oldest commercial method for producing chemical pulp from wood. It originally consisted in digesting suitably prepared wood in a large boiler with a strong solution of caustic soda under a pressure of about 90 pounds per square inch for 10 or 12 hours. The wood was then washed to remove the alkali and treated with chlorine gas or an oxygenous compound of chlorine. The partially digested wood was then washed to free it from the hydrochloric acid formed and again treated with a small quantity of caustic soda solution. The pulp so produced was then washed, bleached, and beaten in a beating engine, after which it was ready for the paper machine. The modification of this process as employed at the present time in the United States dispenses with the intermediate digestion treatment with chlorine compounds. Different cooking conditions also are used, the details of which, together with a brief description of the manner of preparing the wood, are given below.

PREPARATION OF THE WOOD.

While a few mills cook their wood unbarked or only partly barked, the general practice is to remove even the live inner bark.² The

¹ Charles Watt and Hugh Burgess secured a United States patent on this process in 1854. It was developed further and modified by Juillon in France (1855), by Houghton in England (1857), and by Albert Ungerer, to whom a British patent was issued (1872). Further modifications gradually resulted from its commercial application.

² The barking loss amounts to about one-fifth of the weight of unbarked logs. The losses in the case of logs from 31 trees used in these experiments varied from 16 to 20 per cent, which checks quite well with Ziegelmeyer's figure of 19.5 per cent on European aspen. (See Stevens, *Paper Mill Chemist*, p. 150, 1908.) Aside from the convenience and ease of barking in the woods, the saving of freight is considerable when the wood is transported to the mills by railroad, and since the barked wood dries out rapidly an additional advantage is secured by the loss of weight in seasoning. A cord of green aspen (about 50 per cent water) weighs about 1,900 pounds more than the same wood, air dry (about 15 per cent water).

barked or peeled wood is then cut diagonally with the grain into slices or chips about one-half to three-fourths inch thick by means of a machine called a "chipper." These pieces are then further broken up by means of a disintegrator, or "shredder," and the resulting chips are conveyed to storage bins, usually above the digesters. An intermediate screening operation to remove dust and dirt and to secure uniform chips is sometimes given them.

On account of the strong solvent power of the cooking liquors used in the soda process it is not necessary to remove completely the knots or decayed portions of the wood. At some mills, however, the chips before being stored are sorted into different grades from which different qualities of pulp are produced. In the case of peeled wood, delivered as such to the mill, the outer shavings, if the wood is re-cleaned, are kept by themselves and converted into a lower-grade product. In some of the older mills the knots were removed from the peeled logs with a boring machine; and later the chips were picked over by hand. Such procedures, however, have now been practically abandoned in America.

THE COOKING PROCEDURE.

The digesters used in soda-pulp making are either rotary or stationary, and may be either cylindrical or spherical in shape. The present tendency in new installations is towards stationary, vertical, cylindrical digesters heated by live steam which enters at the bottom of the digester in such a manner as to carry the cooking liquor through a pipe to the top of the vessel and spray it over the chips. This insures good circulation. The chips and cooking liquors are charged through a manhole at the top of the digester, the bottom of which is provided with a "blow-off" pipe and valve for discharging the pulp after the cooking is complete. Such digesters are from 15 to 50 feet high by from 4 to 9 feet in diameter. The larger sizes have been lately introduced; in the past the most common size held about one cord of wood and was 16 feet high by 5 feet in diameter. At the time of the 1905 census the average American digester produced about 1 ton of pulp per cook, and the total combined capacity of the 208 soda digesters in operation then was 222 tons of pulp per cook.

As soon as the charging of chips and caustic soda cooking liquors is complete, steam is turned into the digester until a certain cooking pressure or temperature is reached. This temperature varies at different mills, but one corresponding to 110 pounds steam pressure per square inch is probably the most common at present. The pressure is continued from three to eight hours or more.¹

WASHING OF PULPS AND RECOVERY OF COOKING CHEMICALS. *

After the digestion process is completed the pulp in the digester is generally forced out under pressure or "blown" through a pipe

¹ The detailed cooking conditions employed at various mills are shown in the appendix, Tables 16 and 17.

connected with the bottom of the digester into a "blowpit" or "balloon," whence it is transferred to large washing pans. Here it is drained as free as possible from the strong spent cooking liquors, called "black liquors," and washed thoroughly, first with hot, weak, black liquors from the last washings of previous cooks, and lastly with fresh hot water. The first drainings and washings which contain the greater part of the alkali cooking chemicals are run to evaporators, concentrated, and later calcined in furnaces. The burned ash, called "black ash," is leached with water, and the alkali in the form of sodium carbonate is dissolved. The resulting solution is treated with quicklime (CaO), which changes the carbonate into caustic soda. Modern practice recovers from 88 to 92 per cent of the alkali charged into the digesters. By properly controlling the strength of the black ash solution and mixing various strengths of recausticized solutions, a caustic soda liquor of the desired strength for cooking is prepared.¹

TREATMENTS GIVEN THE SODA PULP.

After the pulp has been thoroughly washed it is diluted with a large amount of water and screened to remove uncooked portions. This is accomplished by either flat plate, diaphragm screens, or by such screens in conjunction with centrifugal ones. In the case of aspen or poplar the greater proportion of the water in the pulp is then removed by means of "slushers," "feltless wet machines," or "deckers." The pulp is then treated in a suitable vessel with bleaching-powder solution and afterwards thoroughly washed. Very little aspen or poplar pulp is left in the unbleached state, but is usually bleached immediately after it is screened. Those mills making both pulp and paper generally carry the bleached wet pulp directly through the subsequent paper-making operations; but if the pulp is to be sold or stored it is simply run over a paper machine into rolls of dry pulp (about 10 per cent water).

PREVIOUS INVESTIGATIONS.

The treatises by Cross and Bevan² and by Schwalbe³ and the recent experiments⁴ by Viewig, Miller-Moskan, Miller, Schwalbe, and Schwalbe and Robinoff give much information on the nature of the chemical reactions which take place between caustic soda and cellulose under various conditions, and on the formation of decomposition, mercerization, and other similar products from cellulose.

¹ A few mills still cling to the older practice of not recovering the alkali from the black liquors. Such mills buy the alkali for cooking in the form of caustic soda (NaOH). The cooking solution is produced by dissolving in water a sufficient quantity of the caustic to give a solution of the desired strength. The black liquors are run to waste, and, although the consumption of cooking chemicals is very high, the mills seem to operate at a profit.

² Cellulose, 1903. Also Researches on Cellulose, 1895-1900; 1900-1905; 1905-1910.

³ Die Chemie der Cellulose. 1910-1912.

⁴ For specific literature references see bibliography in appendix.

While the manufacturer of paper pulp is interested in these chemical investigations they do not give him much practical information on the interrelation of the various cooking conditions which he employs and the effect of their modifications on the yield and quality of the pulp.

An article published by Tauss¹ in 1889, dealing with the effects of water alone on cellulose-containing materials, is of interest in connection with the Forest Service tests because the "yield" or residue with zero caustic soda assists in determining the curve for the effect of amount of caustic soda on the yield of crude pulp (fig. 4). Tauss's experiments showed (Table 1) that a very appreciable amount of solids can be extracted from wood and from cellulose by boiling in water, especially at high pressures. In 1890 the same author² published the results of investigations in which caustic-soda solutions were employed in the place of water alone. The experiments with caustic soda were made partly with solutions of a concentration employed in commercial practice, partly with more concentrated, and partly with more dilute solutions.³ The calculated residues (Table 1) afford some interesting comparisons with the Forest Service yield data.

In 1907 De Cew⁴ published a technical article dealing with the function of the soda process in the production of wood cellulose. Although no data are cited to substantiate his conclusions, he makes the following statements:

The results obtained with this process depend very largely upon the accuracy with which it is carried out. The action of caustic soda is one of hydrolysis, in which the woody molecule is gradually broken down with the formation of acid products which combine with and neutralize the alkali, leaving the cellulose in the form of isolated fibers. Now, if sufficient alkali were used and the cooking action continued, the entire fiber would finally be dissolved, although the more resistant celluloses would be the last to disappear. It is, therefore, necessary in order to bring into solution only the lignified portion of the wood to add just sufficient alkali for this purpose.

This is almost entirely neutralized by the acid products formed from the lignocellulose, and thus very little free alkali is left in the liquor to attack the rest of the fiber, which should be almost pure cellulose. At first the alkali is very active and a rapid combination takes place, but the rate of reaction becomes continually slower as the free alkali grows less and the resistance increases. There are also such varying conditions as to causticity, pressure, circulation, and time of cooking, which are of considerable importance in the process, for some makers are obtaining from 1-200 pounds of fiber per cord more than others in treating the same kind of wood.

¹ Dingl. Polyt. J., pp. 276-285, vol. 273, 1889; Jour. Soc. Chem. Ind., p. 913, vol. 8, 1889.

² Ibid., pp. 411-428, vol. 276, 1890; Jr. Soc. Chem. Ind., p. 883, vol. 9, 1890.

³ See footnote, p. 16.

⁴ Jour. Soc. Chem. Ind., pp. 561-563, vol. 26, 1907; Chemical Abstracts, p. 319, 1908.

In regard to the time required for cooking there is a wide difference in practice. However, the most improved plants are now able to effect the complete resolution of the wood in a very short time. In fact, any of the deciduous woods can now be reduced in about four hours. With the improvements in the methods of cooking that have been developed, which enable us to get about twice the work out of a digester that was formerly obtained, a number of special advantages have been found to be the result of these quick cooks. The shorter the time the alkali is in contact with the cellulose, the higher is the yield obtained and the sounder and stronger is the fiber. If all of the cellulose is freed from the lignin at practically the same time, the free alkali will have very little time to react on the weaker celluloses and the fibers will not be broken nor the points and serrations dissolved. Moreover, the fibers from the short cook are not hard to bleach, because the character of the cellulose is uniform. Under conditions of complete saturation with the right proportion of alkali, the lignocelluloses can be almost instantly dissolved by subjecting the material to the temperature and pressure that is ordinarily used for cooking the fiber. The writer has performed this experiment on a laboratory scale, and the fiber obtained so closely resembled the actual structure of the woody cell that hardly any cellulose could have been dissolved.

Clapperton,¹ in 1907, in writing about the soda process, says:

It is the necessity for employing such high temperatures and pressures (90 pounds per square inch) that constitutes the serious drawback to the alkali process as under the conditions of boiling the strong caustic soda acts on the cellulose, impairing the strength and reducing the yield.² The reason why such conditions are necessary is that the soluble acid bodies resolved by the caustic become so oxidized and condensed that they counteract and weaken the reducing action of the soda, and in order to equalize their resistance higher temperatures and pressures have to be employed.

Beveridge³ recently published the results of some of his experiments on the effects of varying the cooking conditions in the production of esparto pulp. He says:

The treatment of esparto by the soda method is typical of the preparation of paper pulp from nearly all fiber-yielding plants, such as bamboo, straw, wood, etc. The isolation of cellulose is brought about by digesting the prepared plant in an alkaline solution, having for its base caustic soda, at variable temperatures and under variable lengths of time. The chemical reaction which takes place during this digesting process is not known; that is to say, has not been isolated because of the complicated character of the encrusting substances surrounding the fiber in the plant. The caustic soda in aqueous solution forms soluble compounds with these encrusting bodies and dissolves any silica which forms a part of the plant's structure, so that by subsequent draining, washing, and bleaching the liberated cellulose is obtained in a comparatively pure state. Cellulose from whatever source it is obtained is, however, soluble in aqueous solutions of caustic soda. Moreover, the solvent action of the caustic is accelerated by heat and by the length of time (within limits) in which the two bodies are heated together. It is therefore apparent that if the maximum yield of cellulose is desired when using this method due regard must be paid to the laws regulating the yield. These laws may be expressed thus: The yield of cellulose obtained from any plant by the caustic-soda method depends upon:

- (1) The proportion of caustic soda (NaOH) used per unit weight of plant;
- (2) The temperature employed; and
- (3) The length of time the digesting operation is continued.

¹ Practical Papermaking, p. 33, 2d ed., 1907.

² In modern commercial practice even higher temperatures and pressures are employed, and the results of the Forest Service tests do not corroborate Clapperton's statements as to the undesirable effects from using them.

³ Papermaker's Pocketbook, p. 72, 2d ed., 1911. See also Sindall, Manufacture of Paper, p. 77, 1908.

If any one of these conditions be altered and the other two kept constant, the yield varies inversely as the altered condition. Thus, in the case of esparto, the author performed a series of experiments in which the proportion of caustic to unit weight of esparto was varied, whilst the temperature and duration of time of digesting were both kept constant with the following results (Table 2).

TABLE 2.—*Experiments regarding yield of air-dry bleached pulp from Oran esparto.*

No. of experiment.	Esparto, weight taken.	Soda liquor.		Conditions of boiling.			Weight of air-dry pulp.	Dry pulp on dry esparto.	Bleaching powder.
		Volume.	Na ₂ O.	Time.	Temperature.	Pressure.			
	Grams.	Cc.	Per cent.	Hours.	°C.	Lbs.	Grams.	Per cent.	Per cent.
1.	200	800	1.58	3	142	55	87.30	43.91	29.5
2.	200	800	2.13	3	142	55	80.67	40.55	18.5
3.	200	800	2.69	3	142	55	72.00	36.20	10.5

NOTE.—The different trials were made in wrought-iron tubes fitted with screw caps, all three being heated together in an oil bath for three hours at a temperature of 302° F. (55 pounds above atmosphere).

The following is taken direct from Cross, Bevan, and Sindall's¹ résumé of Beveridge's experimental results, which include the data quoted in Table 2 and others:

He made three sets of trials, as follows:

Constant conditions.		Variable.
1. Time and strength of caustic.		Pressure varied.
2. Pressure and time.		Strength of caustic varied.
3. Pressure and strength of caustic.		Time varied.

The results were:

1. Increase of pressure resulted in a diminution of yield, the quantity of pulp obtained being reduced considerably.
2. Excess of caustic soda caused rapid diminution in the yield of cellulose.
3. Gradual exhaustion of the caustic soda by prolonged digestion prevented such serious diminution of yield.

The discussions and experimental results which have been quoted show in a general way the effects of varying some of the fundamental cooking conditions in the soda process. None of the experiments cited are directly comparable to commercial practice in this country, because the testing conditions were not sufficiently representative of manufacturing conditions, and, in the case of Beveridge's experiments, because esparto—a grass, or pectocellulose—was used as the test material. Moreover, the effects of the cooking conditions employed were not studied in as great detail as seemed desirable. The experiments show very clearly, however, that improper cooking conditions are wasteful or inefficient, and indicate the need for complete experimental data on which improvements in commercial practice may be based.

¹ Wood Pulp and Its Uses, p. 132, 1911.

METHOD OF CONDUCTING EXPERIMENTS.

SCOPE AND PLAN OF TESTS.

Aside from the character of a wood or other material prepared for cooking, the principal cooking conditions affecting yields and properties of pulps, consumption of cooking chemicals, and the general efficiency and costs of the cooking operations are indicated under the following general headings:

- (1) Preliminary treatments which may in some cases be given the prepared chips. This includes such treatments as preliminary pressure, vacuum, or steaming.
- (2) Character of the cooking apparatus, including size, shape, and construction of the digester; manner of heating, whether by saturated or superheated steam turned directly into the digester, or by the use of steam jackets or flue gases; also the degree and kind of mechanical agitation employed, if any.
- (3) Proportions of the charges. This covers the amounts of wood and chemicals; also the amounts of water present in the wood and the original cooking solutions together with the water condensing in the charges from steam used in cooking.
- (4) Character of the cooking liquors when charged. Such items as causticity, initial temperature, impurities, and concentration are important.
- (5) Duration of the cooking treatment. The treatment is in three periods—(a) a period of increasing temperature; (b) a period at maximum temperature; and (c) in some cases, a period of decreasing temperature.
- (6) Pressures and temperatures. This considers the pressures and temperatures of the digester contents at different stages of cooking; also the temperature of the digester room (as affecting radiation and condensation).
- (7) Manner of admitting steam, "relieving," and "blowing" the digester.

Since the effects of the variable cooking conditions may be modified by the treatments given the pulps after leaving the digester—such as leaching or washing, screening and bleaching—these treatments must also be taken into account, for it is not possible to determine all the important effects of the cooking treatments until the finished pulps have been prepared.

The many factors are more or less interdependent, and any change in one results in unavoidable changes in others. Four of the more fundamental of these factors have been investigated in the Forest Service experiments. They are:

- (1) Amount of caustic soda charged per pound of wood.
- (2) Duration of cooking at maximum temperature.
- (3) Maximum temperature (pressure) of cooking.
- (4) Initial concentration of the cooking chemicals.

The effect of these four factors upon the yield and properties of the pulp and the consumption of cooking chemicals were determined.¹

¹ The purely chemical aspect of the cooking action has not been given special consideration. The effect of the caustic soda cooking liquors under the conditions employed in pulp making is recognized as a hydrolytic action in which the caustic soda extends the limits of hydrolysis. This subject has been given careful attention by Cross and Bevan, Schwalbe, De Cew, and others as indicated in previous references. The effects of the cooking conditions on the recovery of soda also have been given no consideration except in a very cursory manner. The laboratory facilities did not permit this important subject to be studied at the time of the experiments.

The tests fall naturally into four groups; in each group all the conditions were held as nearly constant as possible except the factor under investigation, which was varied in successive tests or "cooks" according to a definite plan. The plan of the tests is shown in Table 3. In addition to the factors mentioned in this table all other factors under control were so far as possible held constant. Those for which values were specified are the following:

Amount of chips for each charge, 40 pounds bone-dry weight.

Dryness of chips, air dry.

Causticity of cooking liquors, 95-98 per cent.

Temperature of charging cooking liquor, 22° C. (72° F.)

Temperature of digester room, 22° C. (72° F.)

Duration of cooking before maximum pressure is reached, 1 hour.

Duration of cooling and relieving digester before blowing, 5-10 minutes.

Blowing pressure, 30 pounds per square inch.

TABLE 3.—*Plan of cooking experiments.*

Test group.	Number of tests.	Cooking conditions under investigation.			
		Initial concentration of caustic soda in digester liquors. ¹	Amount of caustic soda per 100 pounds of wood. ¹	Maximum cooking temperature (equivalent steam pressure).	Duration of cooking at maximum pressure or temperature.
I.	6	Constant—80 grams per liter.	Variable—from 15 to 40 pounds in steps of 5 pounds each.	Constant—100 pounds per square inch.	Constant—6 hours.
II.	6	Same as Group I....	Constant—25 pounds (value selected from Group I tests as most satisfactory for later tests).	Same as Group I....	Variable—from 1 to 11 hours in steps of 2 hours each.
III.	6	do	Same as Group II....	Variable—from 70 to 120 pounds per square inch in steps of 10 pounds each.	Constant—7 hours (value selected from Group II tests as most satisfactory for later tests).
IV.	4	Variable—from 110 to 50 grams per liter in steps of 20 grams each.	do	Constant—100 pounds per square inch (value selected from Group III tests as most satisfactory for later tests).	Same as Group III.

¹ In commercial practice it is customary to vary the amount of chemical used and its initial concentration both at the same time when attempting to change the severity of the cooking due to these factors. This results in the volume of the cooking liquors being kept approximately the same, which is a desirable feature. In these tests, however, it was the intention to find out the effects of each factor separately.

TESTING PROCEDURE.

The apparatus employed in cooking is shown in figure 1. Figure 2 shows diagrammatically the course of the material through the various stages of treatment and testing, and in this way the relation of one part of the procedure to another is made clear.

After the amount of moisture in the chips had been ascertained by means of sample A, the charge was weighed out and put into the digester. Caustic soda solution, of the desired concentration and volume, had been prepared by diluting the necessary quantity of analyzed stock solution (sample B) with water. It was then heated

to the charging temperature and run into the digester, and the cooking operation was begun by permitting live steam to enter at the bottom.

During the cooking, observations were made at 15-minute intervals of (1) digester temperature, (2) digester pressure, (3) steam pressure at digester inlet, and (4) room temperature. The volume of liquor

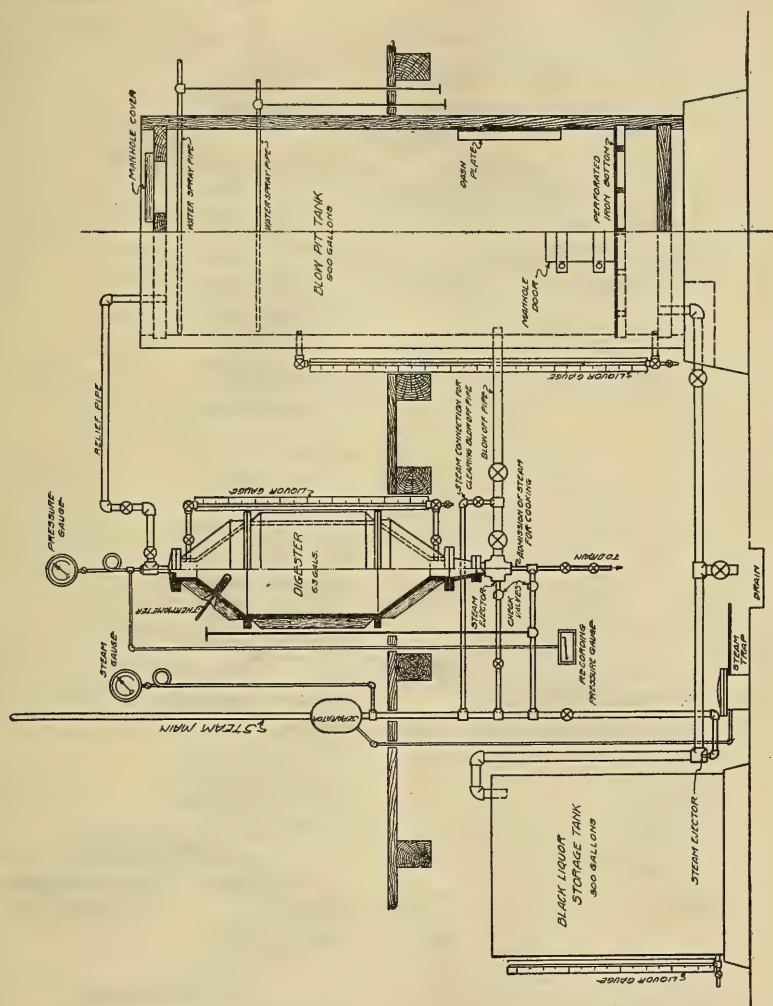


FIG. 1.—Experimental equipment for cooking by the soda process.

in the digester was also observed, but at hourly intervals. These observations were recorded, and a graphic "log of cook" was made at the same time, an example of which is shown in figure 3. If at any time the digester temperatures and pressures as observed on the thermometer and pressure gauge did not agree when compared by means of pressure-temperature tables for saturated steam, the excess of pressure was relieved; such a condition occurred as a rule only dur-

employed, and were held constant at this value during the remainder of the cook. At the end of the cooking period the top relief vent was opened and the digester pressure quickly "relieved" until "blowing pressure" was reached, when the vent was closed, the two blow-off valves were opened, and the digester was emptied under blowing pressure with the assistance of a steam ejector in the blow-off line.

The pulp was caught in the blow pit, where it was washed with three or more 50-gallon applications of hot water. After the blowing and after each successive washing the pulp was allowed to drain, and the drainings were pumped to the black-liquor storage tank. The washing operations were continued until the last drainings were of a specific gravity lower than 1.003 at 22° C. Inasmuch as the top relief pipe emptied into the blow pit, it was possible to collect the small amount of relief liquors, together with the black liquors, in the storage tank, where the volume of the whole was read off on the graduated tank gauge. A sample of this

(sample C) was secured for analysis, and the amount and character of the recovered chemicals determined. (Fig. 2.)

After the last washing the crude pulp in the blow pit was drained as dry as possible and, by means of scoops, removed to a strong linen bag inclosed in a perforated metal cylinder. The pulp in this form was then placed under a 70-ton, knuckle-joint, power press. After being pressed to about 30 per cent bone dry the pulp was next

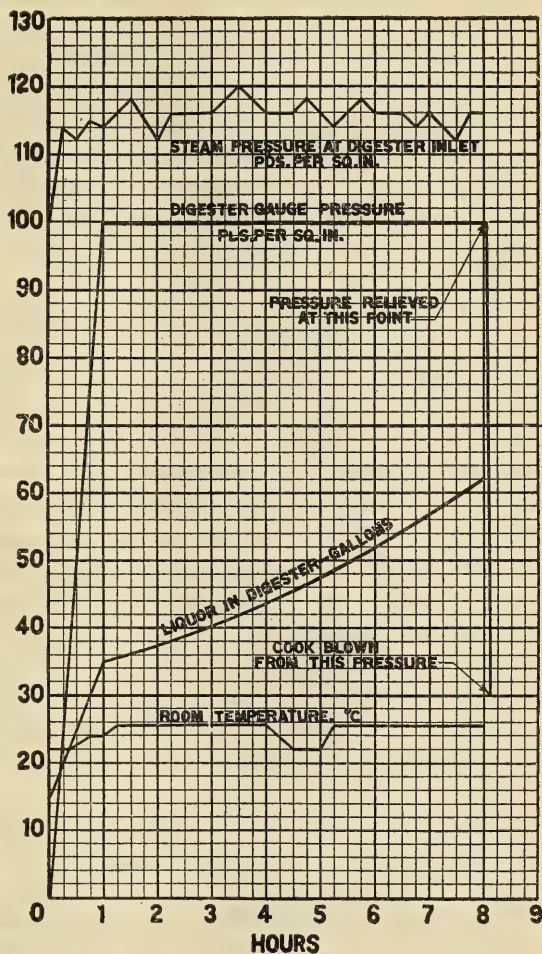


FIG. 3.—Typical graphic log of cook. (Cook 24.)

"opened up" in a swing-hammer shredder running at low speed and without a cage, so that the largest lumps after shredding were about hazelnut size. This was done to facilitate sampling and increase the accuracy of the dry-weight determinations. The shredded pulp was weighed and sampled (sample D) for determining the dry weight. It was then mixed with water and further opened up in a 25-pound Hollander-style beater, with the roll well off the bedplate so that no real beating could take place, and was pumped from the beater to a 200-gallon stock tank at the head of the screening system, where it was diluted with water to a known volume. This mixture was then screened by means of a 6-plate diaphragm screen with slots 0.009 inch wide. The screenings which went over the plates were then collected, weighed, and sampled (sample E), as described for the crude pulp. The screened, unbleached pulp which went through the screen slots, mixed with a large amount of water, was run to a water extractor and concentrated. Afterwards it was pumped to the paper machine stuff chest, made up to a known volume with water, pumped to the machine screen (diaphragm type, 0.012 inch slots), and run out on a 15-inch Fourdrinier paper machine (see Pl. I), into a sheet 10 inches wide by about 0.010–0.011 inch thick. The rolls of the screened, unbleached pulp thus secured were stored awaiting the tests to determine its properties for which samples G to R were taken. Where the screenings were so large in amount as to preclude accuracy of sampling the crude unscreened pulp, such pulp was screened without the preliminary pressing, shredding, etc., and the screened pulp was collected on a 70-mesh sieve, pressed, shredded, weighed, and sampled for the yield determinations. The pulp was then screened again and made up into a sheet as described.

The methods used for determining dry weights, yields, quality of pulps, and composition of liquors are given in the appendix.

TEST MATERIALS USED.

WOOD.

The test material consisted of 31 logs of aspen (*Populus tremuloides*, Michx.) cut from representative trees growing intermixed with white birch near Rhinelander, Wis. The trees were of seed growth and had attained an average height of 44 feet, with straight, clear lengths of about 22 feet from which the logs were cut.

The ages of the logs varied from 28 to 42 years, as determined by counting the annual rings. The logs were fairly free from knots, considering the size of the trees and the species. Volume-weight determinations on 36 samples, representative of the whole shipment, showed the average bone-dry weight per cubic foot of green or

unseasoned wood free from knots to be 26.68 pounds. The samples ranged from 23.6 to 31.4 pounds per cubic foot.

As a rule the test material was sound, but some of the logs had decayed hearts. The material was peeled by means of a carpenter's drawknife; all decayed portions on the outside of the pieces and all protruding knots were chopped off. This cleaned wood was then sawed into disks five-eighths inch thick in the direction of the grain. Butts, tops, and all disks containing decay or other defects were culled.

The remaining sound disks were split with the grain into chips 1 inch to 6 inches by one-fourth inch by means of a special guillotine chipping machine. All knots were culled. The chips were then seasoned to constant air-dry weight, thoroughly mixed and screened to remove sawdust and dirt, and finally stored in cans to await the cooking tests.

COOKING CHEMICALS AND SOLUTIONS.

In ordinary mill practice the soda cooking liquors are made as described on page 4. The freshly causticized solution contains caustic soda (NaOH) for the most part, but a small amount of soda ash (sodium carbonate, Na_2CO_3) still remains uncausticized. Various impurities are also present, but these are considered to have no effect in cooking.

In the experiments the cooking solutions were made by dissolving fused caustic soda, 76 per cent¹ sodium oxide (Na_2O), in water. The resulting solution was similar to the solutions used in commercial practice so far as caustic soda and soda ash are concerned, and there is no reason to believe that the results should be different in any way from those which would have been obtained by the use of commercial liquors of the same concentration and causticity.

EFFECTS OF VARIATIONS IN THE COOKING CONDITIONS.

The influence of the variable cooking condition in each group of tests on resultant yields and properties of pulps and consumption of cooking chemicals is shown graphically in figures 4 to 15.² The same results in greater detail are given in Tables 10 to 14 of the appendix. While, in general, the tests were carried out in accordance with the plan which has been described, minor departures could not be avoided, and the location of certain points on the diagrams are more or less affected by such variations. For this reason the tabulated data should be consulted for the exact conditions of each cook.

¹ Manufacturer's analysis.

² The numerals opposite each platted point on the curves are the serial numbers of the cooks. (See Tables 10 to 14.)

YIELDS.

The effects on yields of pulp and screenings are expressed by the curves in figure 4, in which the yields are plotted against the amount of caustic soda, the duration of cooking, the pressure of cooking, and the initial concentration of caustic soda.

AMOUNT OF CAUSTIC SODA.

With increases in the amount of caustic soda per pound of wood the yield of total crude pulp decreased at the rate of about 1 per cent for each 2 per cent of caustic (0.02 pound NaOH per pound of

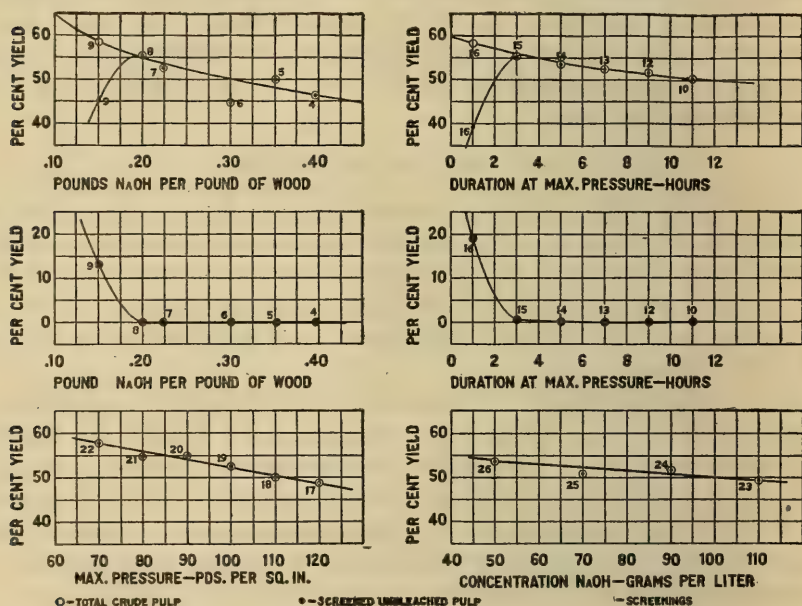


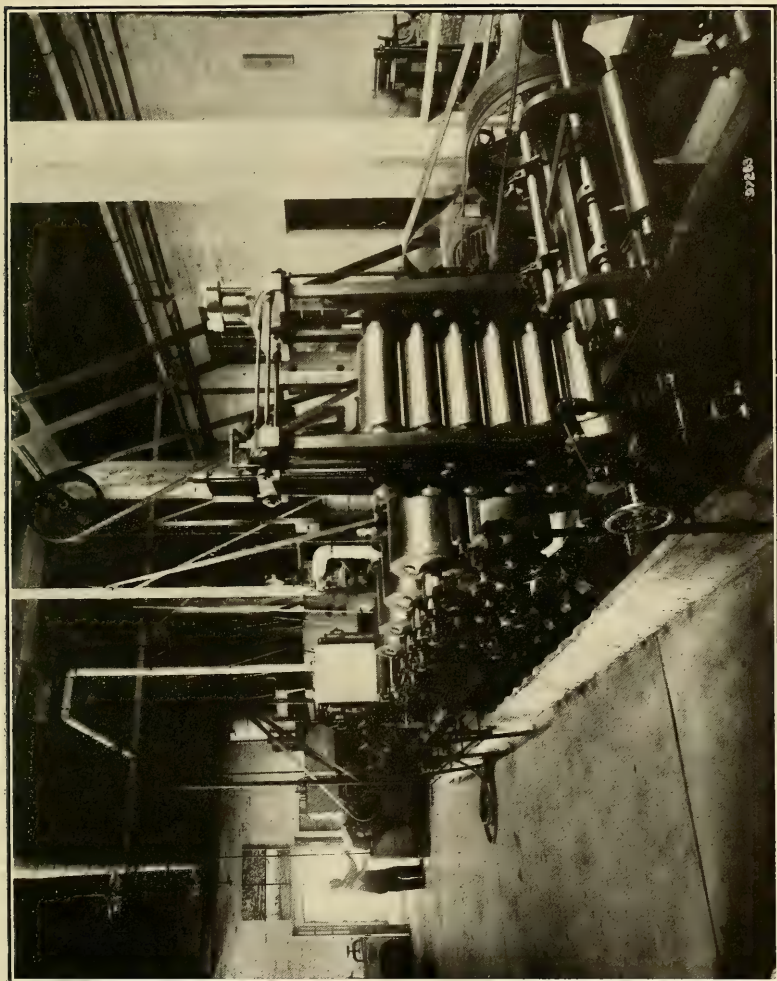
FIG. 4.—Effects of cooking conditions on yields of total crude pulp, screened unbleached pulp, and screenings.

wood). The yield at zero caustic soda would probably fall between 80 and 90 per cent, being influenced only by the cooking effect¹ of the water condensed from the steam used in cooking. For high amounts of caustic soda the curve tends to approach parallelism with the horizontal axis. The yield would not be expected to become zero unless exceedingly large amounts of caustic were used.²

For amounts of caustic soda above what may be considered the minimum for successful cooking under the conditions used, the yield

¹ See Tauss's experiments, Table 1.

² Tauss used for a single boiling as high as 7 pounds of caustic soda per pound of wood, and the yield or undissolved material after three hours at 58.8 pounds per square inch steam pressure amounted to 8.52 per cent for beech and 2.87 per cent for pine. With 4 pounds caustic soda per pound of wood in each of three successive three-hour treatments under a steam pressure of 132.3 pounds per square inch, the yields for the two woods were 20.61 per cent and 18.20 per cent, respectively. This latter proportion of caustic soda was ten or more times as great as is ordinarily employed in commercial practice. Also the other cooking conditions were proportionately more severe.



PAPER MACHINE, FOREST PRODUCTS LABORATORY, MADISON, WIS.

of screened unbleached pulp was identical with that of crude pulp, but for smaller amounts of chemical it rapidly approached zero, while under the same conditions the screenings curve naturally approaches and becomes coincident with the curve for the total crude pulp. In this group of tests the minimum amount of caustic soda for successful cooking, so far as yields alone are concerned, is somewhere between 15 and 20 per cent.

DURATION OF COOKING.

The duration of cooking at maximum pressure influenced the yields in very much the same manner as did the amount of chemical. The yield of total crude pulp decreased about 1 per cent for each additional hour of cooking at maximum pressure. However, the curve (fig. 4) seems to approach parallelism with the horizontal axis, thus signifying that beyond a certain point cooking would have had no further effect.¹ The time allowed for these cooks to reach the maximum pressure was one hour, and the extended curve indicates a yield of about 60 per cent for zero hours duration at maximum pressure. This shows that the greater part of the cooking was accomplished during the first hour, or before the maximum pressure was attained, since during that hour about 40 per cent of the wood substance had been dissolved and the dissolving effect during the next 12 hours was only one-fourth as great.

As determined by the yield curves, the minimum duration for successful cooking under the conditions employed was between one and three hours at maximum pressure. No tests were made between these two points.

PRESSURE OF COOKING.

The curve showing the influence of maximum cooking pressure or temperature on yields indicates that all of the tests were made at pressures above the minimum required for successful cooking, under the conditions employed for these tests; hence, no screenings were obtained from any of the cooks, and the curve for screened unbleached pulp coincides with that for total crude pulp. Increases of pressure from 70 to 120 pounds per square inch resulted in decreasing the yields of pulp about 1 per cent for each five pounds, which indicates that the higher pressures increase the thoroughness of cooking, other conditions being constant.

CONCENTRATION OF CAUSTIC SODA.

The tests varying the initial concentration of caustic soda in the digester liquors were also made within limits that resulted in thorough cooking for all of the tests. Increasing the concentration under the

¹ Figures 12 and 13 show that the active cooking chemical was consumed at the end of 7 hours at maximum pressure; it is therefore not apparent from these tests what would be the effect of continued cooking in the presence of available caustic soda.

conditions employed resulted in decreasing the yields of pulp about 1 per cent for each 13 grams per liter increase in concentration. It is thus evident that with a given amount of chemical the greater cooking effect is secured by means of the more concentrated solutions. A practical limit of course exists at the point where the volume of the digester liquor becomes too small to afford favorable cooking conditions.¹

PROPERTIES OF UNBLEACHED PULPS.

NATURAL COLOR.

Curves indicating the effects of the conditions of cooking on the natural color of the unbleached pulps are shown in figure 5.

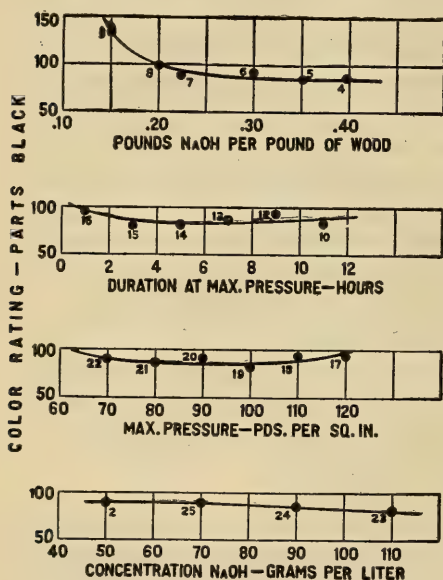


FIG. 5.—Effects of cooking conditions on the color ("parts black") of pulp.

ing was increased. This was probably due to the pulp fibers absorbing and retaining coloring matters from the "black liquors." It is generally believed that as the cooking becomes more thorough the cellulose of the fibers gradually becomes more gelatinous or hydrated, and would therefore tend to retain coloring matter during the subsequent leaching and washing treatments.

The pressure (temperature) of cooking seems to have had comparatively little effect on the color of the pulp within the range investigated.

¹ As the initial concentrations increased, the volumes of digester liquors at the start of cook decreased (see fig. 17), since the amount of caustic soda was held constant. Hence, increasing concentrations would eventually result in a volume of digester liquor so small that the whole charge of chips would not be covered until late in the cooking period after the liquor had been sufficiently diluted by the condensed steam used in cooking. In this case part of the chips would receive very severe treatment, while the remainder would more or less escape the cooking effect. The resulting pulp would represent a composite of the two conditions.

The more thorough cooking resulting from the higher initial concentrations of caustic soda produced lighter-colored pulps, although the lower limit of the cooking condition in these tests was considerably above the minimum for successful cooking.

While the several curves shown in figure 5 indicate for each group of tests more or less change in the "parts black" color ratings or the depth of color, the hues of the pulps were not materially affected.

OCCURRENCE OF SHIVES.

Shives are most numerous in pulps from the less severe cooks and are entirely absent from those thoroughly cooked. The shives curves (fig. 6) bear some resemblance to those for the yields of screenings, but shives disappear from the pulps only under somewhat more severe cooking conditions than those which reduced the yield of screenings to zero. At the point of maximum yield of screened pulp the cooking has progressed far enough for the fibers to become more or less separated from each other, but not completely so, since some of them still remain in groups (shives) small enough to pass the screen slots. But as the cooking becomes more severe the fibers are entirely separated, and the resulting pulp is free from shives. In gen-

eral, increasing the amount of caustic soda, the duration or the temperature of cooking, or the initial concentration of the digester liquor decreases the "shiviness" of the pulp.

ASH CONTENT.

The curves in figure 7 indicate that increasing the thoroughness of cooking within certain limits decreases the ash content of the pulp; outside of these limits the ash content may be increased.

Since the normal amount of ash in aspen wood is not over three-quarters of 1 per cent, the high amounts in the pulps produced

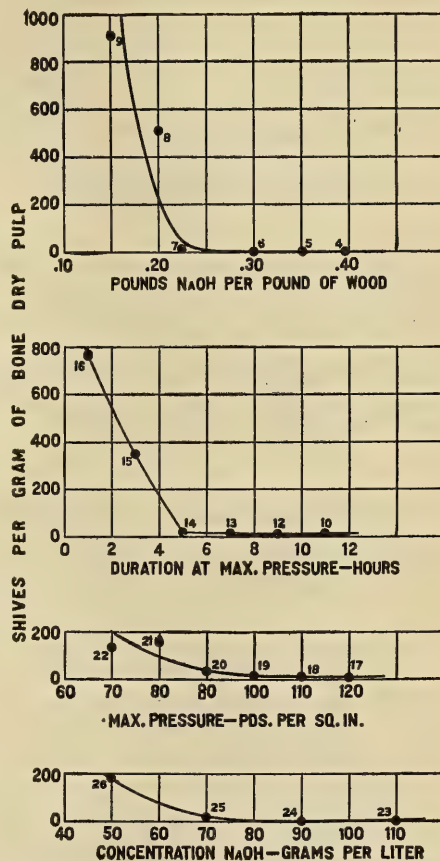


FIG. 6.—Effects of cooking conditions on the occurrence of shives in pulp.

from this wood in some of the tests is probably due to the presence of cooking chemicals¹ which were not completely removed during the washing treatments. Increasing amounts of ash as the cooking conditions become more severe may be due to a difference in the physical character of the cellulose produced under such conditions and the resultant increased difficulty of leaching out and washing away any residual and absorbed mineral matters. No tests were

made to determine the character of the ash from any of the pulps.

STRENGTH.

The strength of a pulp depends chiefly upon three factors—(1) the strength of the individual fibers; (2) the felting or matting quality of the fibers; and (3) the presence of gelatinized fibers and other matters which act as cementing materials.

Severity of cooking is attended by a weakening of the cell walls and may result in a decrease in the strength of the pulp. This decrease of strength was strongly marked in the tests in which the more severe cooking conditions were produced by increasing the amount of caustic soda. It was most rapid up to the point where the fibers

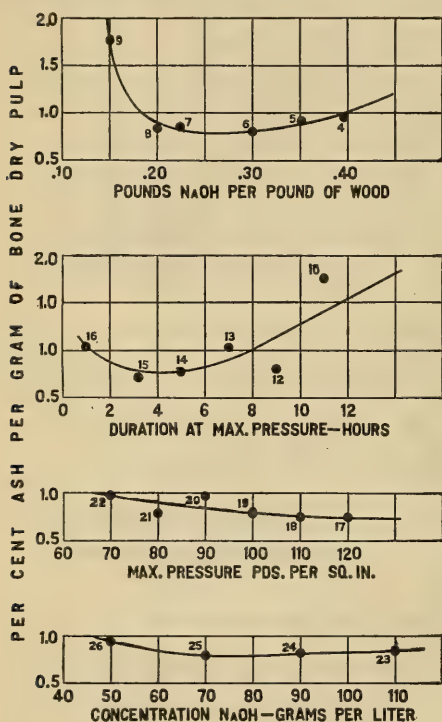


FIG. 7.—Effects of cooking conditions on the ash content of pulp.

were completely separated (indicated by the absence of shives), beyond which it was less pronounced. For increasing durations of cooking the general trend² of the effect was the same as for increasing amounts of chemical, but the total decrease in strength was not quite so great in amount for the range of cooking conditions investigated.

¹ Special precautions were taken to eliminate the influence of dirt. Further it does not seem reasonable that the cooking action which removed the lignin and other organic matters should have produced in the fibrous residue or pulp a concentration of the mineral constituents which go to form the wood ash.

² The data are not sufficient for expressing the effect in detail. The true curve would be expected to have a bend coinciding with the point of maximum yield of screened pulp or the point where the shives are reduced to zero.

Increasing the pressure and increasing the initial concentration beyond a certain point both increased the strength of the pulp. This effect is apparently contradictory to that found for the other two groups of tests and may possibly be due to the high temperatures and high concentrations which would tend to cause a physical change in the cellulose with increase of the cementing effect mentioned previously.

Curves showing the influence of cooking conditions on the strength of pulp are given in figure 8.

EASE OF BLEACHING.

The chief purposes of bleaching are (1) to produce a white pulp and (2) to destroy any non-cellulose materials which tend to make the pulp less durable. The more nearly the original pulp approaches to pure cellulose the less is bleaching required. However, difficulty of bleaching is occasioned not only by the presence of ligneous matters, but also by coloring matters absorbed in the cell walls from the "black liquors" and by the residual cooking chemicals which the leaching and washing treatments have failed to remove. In the latter case a certain amount of bleach is neutralized by reactions with the other chemicals.

Curves expressing the effects of varying the cooking conditions on the ease of bleaching, as measured by the amount of bleach required to bring the pulps to a standard white color, are shown in figure 9. These curves show that under the conditions of cooking the residual ligneous matters are the most important factor in determining the amount of bleach required, since the more thorough cooking produces pulps that are more easily bleached. The decrease in amount of

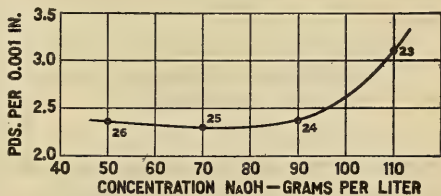
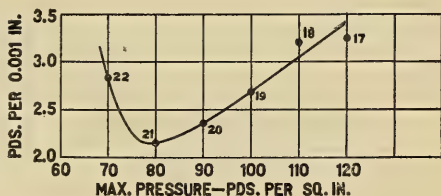
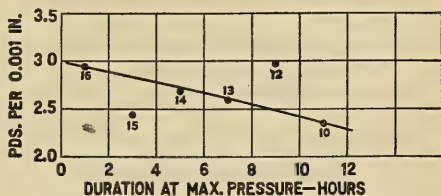
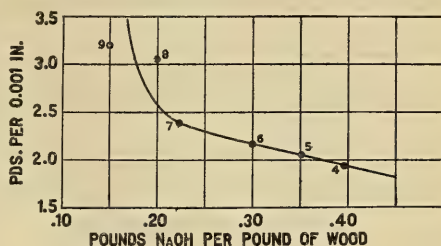


FIG. 8.—Effects of cooking conditions on the strength of pulp.

bleach required was very rapid up to the point where shives were eliminated; beyond this point the effect was less marked. It must not be assumed, however, that the shives alone necessitated the larger amounts of bleach. The presence of shives indicates an incomplete cooking reaction and implies that considerable ligneous matter may remain in the other (completely separated) fibers.

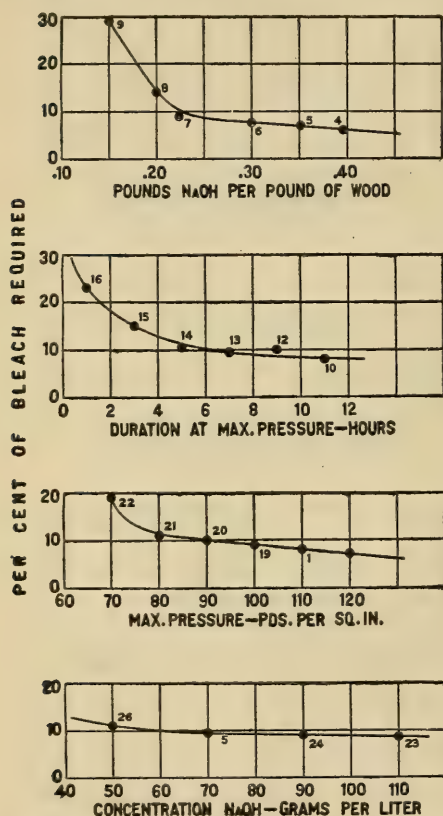


FIG. 9.—Effects of cooking conditions on the ease of bleaching.

approach parallelism with the horizontal axis. Such an effect was obtained for the tests in which the cooking pressures were varied. It is not reasonable to believe that more severe cooking would result in pulps which would suffer no loss whatever on bleaching.

The platted points for the tests in which the initial concentrations were varied are so few in number and so irregular in location that they give little indication of the influence of this factor. However, additional information is obtained from some earlier tests of the Forest Service, summarized in Table 4.

The effect of severity of the cooking conditions is especially noticeable in the curves for the tests varying the amount of caustic soda and the duration of cooking, since certain of the pulps produced in these tests were less thoroughly cooked than any of those from the other groups.

LOSS ON BLEACHING.

The curves showing the losses on bleaching as affected by the varying cooking conditions are given in figure 10. As would be expected, the loss decreased with thoroughness of cooking. In the tests varying the amounts of chemical and the durations of cooking the rate of decrease in bleaching loss with greater severity of cooking was fairly constant, but it is probable that if the cooking conditions were extended for higher values than those used the curves would

TABLE 4.—*Effect of concentration on bleaching losses (autoclave tests).*¹

Cook No.	Concentration of NaOH.	Yield of total crude pulp.	Yield of screenings.	Bleach required.	Loss on bleaching.
	<i>Grams per liter.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1	80	41.10	0.10	15.4	3.92
2	50	44.23	.03	14.7	4.08
4	30	46.97	.07	15.8	4.68

¹ Each cook employed seven hours' duration at 110 pounds pressure per square inch. The caustic soda charged amounted to 0.25 pound per pound of wood. For complete information see appendix, Table 15.

These data indicate that increasing the concentration reduces the loss on bleaching, hence the curve in figure 10 has been drawn to show such an effect. This is substantiated by the fact that varying the amount of chemical and the duration and pressure of cooking in each case showed a reduction in the bleaching losses as the severity of cooking increased, and that most of the other curves for the effect of concentration (especially the yield, shives, and bleach-required curves) show more severe cooking with the higher concentrations.

The relatively large amount of loss in the case of cook 23 does not seem to be warranted in view of the well-cooked condition of the pulp. However, the comparatively high strength of the pulp indicates an abnormal condition.

The loss in weight of a pulp during bleaching is due primarily to the removal of the colored ligneous matters and to the partial destruction of the cellulose itself. The latter is especially liable to occur if the bleaching treatments are severe, or if the cooking treatments have left the cellulose in an easily oxidized condition, so that it is either dis-

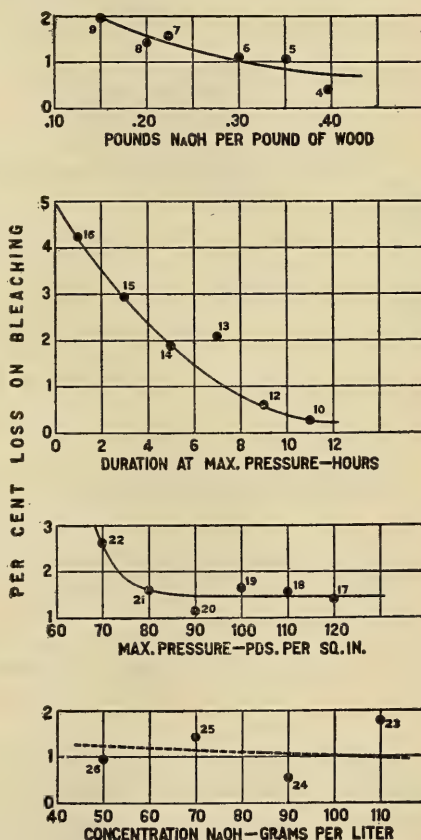


FIG. 10.—Effects of cooking conditions on the bleaching loss.

solved during bleaching or broken up into small particles, which are removed in the washing operations. The partial removal of the mineral or ash-forming constituents from the pulp may also occasion some loss. On the other hand, the ash in bleached pulp sometimes tends to increase over that for the unbleached pulp (due to an accumulation of lime compounds and other residues from the bleaching solution), and hence may offset the loss due to other causes.

RELATION BETWEEN PROPERTIES AND YIELDS.

Many of the curves expressing the effects of the varying cooking conditions on the properties of the unbleached pulps have bends or

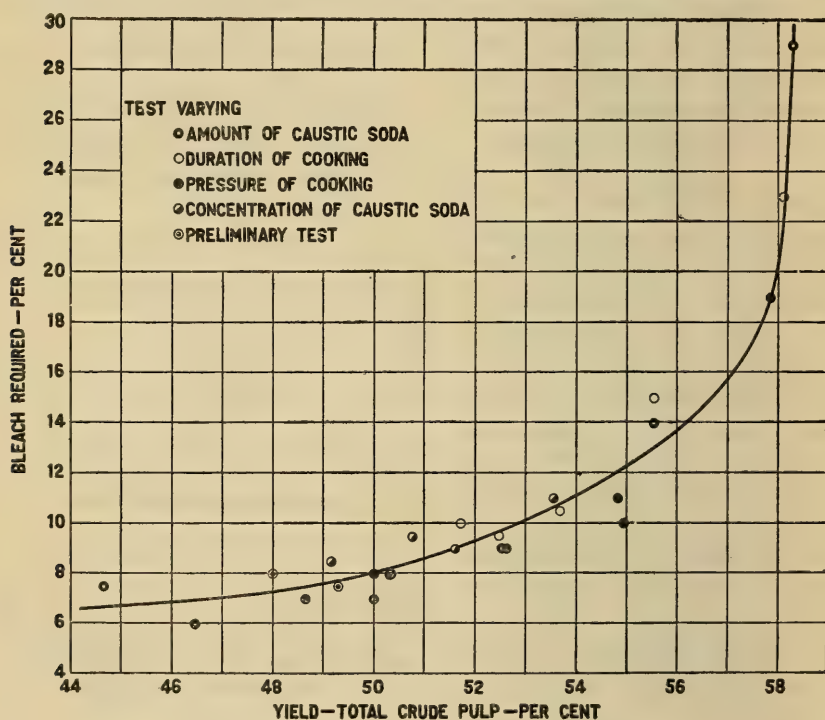


FIG. 11.—Relation between yields and ease of bleaching.

“breaks” at or near the values for the cooking conditions which resulted in the highest yields of screened pulp. So general is this that, with decreasing severity of cooking, the occurrence of sudden changes of direction for curves expressing properties affords a reliable indication that the yield of screened unbleached pulp is near its maximum. This is especially evident in the curves for ease of bleaching.

That properties of pulps are directly dependent upon yields is well illustrated when amounts of bleach required are platted against yields of total crude pulp, as in figure 11. Values for all of the cooks made in these experiments have been platted, irrespective of the testing

conditions under which they were secured. It is evident that cooks which resulted in decreased yields produced easier bleaching pulps. For the higher values slight differences in yields are accompanied by marked differences in the ease of bleaching, but the effect rapidly diminishes until a large decrease in the yields affords little difference in the amounts of bleach required. This would be expected in view of the nature of the cooking reactions. The effect is first to remove the intercellular substances and part of the ligneous matters from the wood, then the cellulose itself begins to be attacked, and finally, after the greater part of ligneous matters has been removed, the cellulose alone is affected. The ease of bleaching is a measure of the amount of noncellulose matters present in the pulp.

Other properties of the pulps when similarly platted against yields show more or less definite relationships, but are apt to be modified according to the cooking condition varied. For instance, when varying the amount of caustic soda or the duration of cooking, decreased yields were attended by decreased strength of pulp; when initial concentrations or pressures were varied, the strength increased as the yields decreased. Natural color, shives, and screenings, however, were little affected for yields below 54 per cent, no matter how produced; for higher yields the color, shives, and screenings increased rapidly with increasing yields. The losses on bleaching followed fairly closely the amounts of bleach required, and hence decreased as the yields decreased.

SIGNIFICANCE OF PROPERTIES.

There are at present no accepted standards of quality or market grades of soda pulps. What may be sufficiently good quality for one purpose or one mill may be poor or medium quality for another. Aside from bulkiness and opacity, which depend mainly on conditions not studied in these experiments, the desirable properties of a pulp are, in general, as follows:

- (1) Low percentage of bleach required.
- (2) Low loss on bleaching.
- (3) High strength.
- (4) Durability (resistance to wear and decomposition).
- (5) Low ash content.
- (6) Few shives.
- (7) Absence of dirt.
- (8) Light color for the unbleached pulp.
- (9) Whiteness of the bleached pulp with freedom from certain undesirable tints.

It is not often that any one pulp has the advantage over another in all of these properties, and for many uses some of them are of no importance. For aspen (poplar) or other short-fibered pulps used in the manufacture of book papers the properties which are given most

consideration are freedom from dirt and shives and low percentage of bleach required, with the attendant low loss on bleaching. Both undercooked and overcooked pulps are to be avoided.

CONSUMPTION OF CAUSTIC SODA.

By consumption of caustic soda is meant the neutralization of the free or active caustic soda (NaOH) existing as such in the digesting

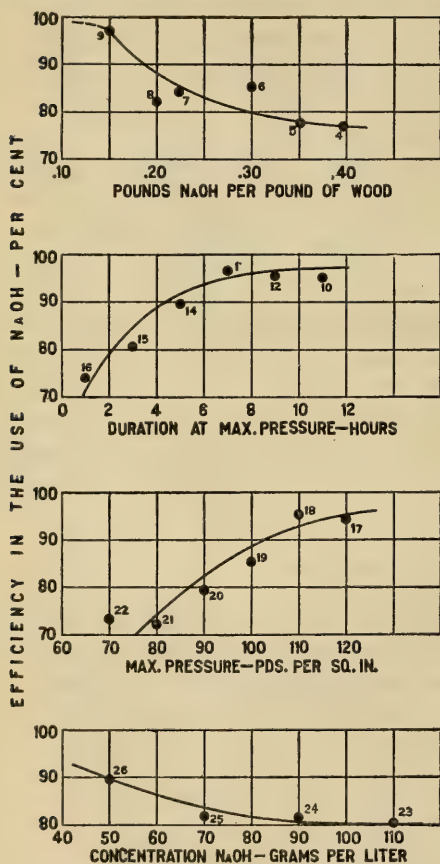


FIG. 12.—Effects of cooking conditions on the efficiency in the use of caustic soda.

liquors. The neutralization results from the combination of the sodium (Na) of the alkali with the acid products derived from the hydrolysis of the lignified fibers during cooking.¹ The black liquors at the end of the cooking treatments contain in dissolved form these nonalkaline, sodium compounds, together with the remaining free caustic soda.

The effects of varying the cooking conditions on the consumption of caustic soda, expressed in per cent of the amount charged or the efficiency in its use, are shown in figure 12. The actual consumption in pounds per 100 pounds of wood is shown in figure 13.

As would naturally be expected, the greatest comparative efficiency for the cooks made with varying quantities of caustic soda resulted from the use of the smaller amounts. However, when very small amounts were employed, the

¹ See De Cew's discussion, p. 6.

² It is a well-known chemical law that in order to carry a reaction to a given degree of completion for one of the reacting substances it is necessary to have available a certain excess of the other chemical or chemicals which take part in the reaction. This means that the efficiency in the use of the chemical can not be 100 per cent. The speed of the reaction is proportional to the amount of the excess.

With increasing durations of cooking the efficiency in the use of caustic soda increased until it reached a constant maximum value. An efficiency of 95 per cent was obtained by seven hours' cooking at maximum pressure, and, since no greater efficiency was secured by continuing the cooking four additional hours, it is apparent that this represents the maximum efficiency attainable. That the cooking reactions are not due entirely to the presence of active caustic soda is indicated by the fact that after the 95 per cent efficiency had been attained increased durations resulted in some further cooking effect¹

(see curves for yields and properties of pulps) with no increase in the amount of chemical consumed. Increasing the pressure also resulted in greater efficiency in the use of caustic soda until a maximum of 95 per cent was obtained.

In all groups of tests in which a constant amount of caustic soda was charged into the digester for each cook, greater percentage efficiency in its use could mean only a greater actual consumption of the chemical. In the group of tests varying the amounts of caustic soda, the decrease in percentage efficiency was accompanied also by increase in the actual consumption. It is thus apparent that the more thorough cooking, whether produced by increasing the amount of chemical in the charge or the duration or the pressure of cooking, is, in large part at least, due to the greater completeness of the reaction between the chemical and the wood.

The tests employing various initial concentrations of caustic soda in the digester liquors (the amount of caustic soda charged remaining the same) seemingly do not bear out this conclusion. In most respects the determinations of yields and properties of the pulps in these tests indicated that the more concentrated solutions resulted in more thorough cooking, but no increase in the consumption of chemical occurred; in fact, with increase of concentration, a decrease

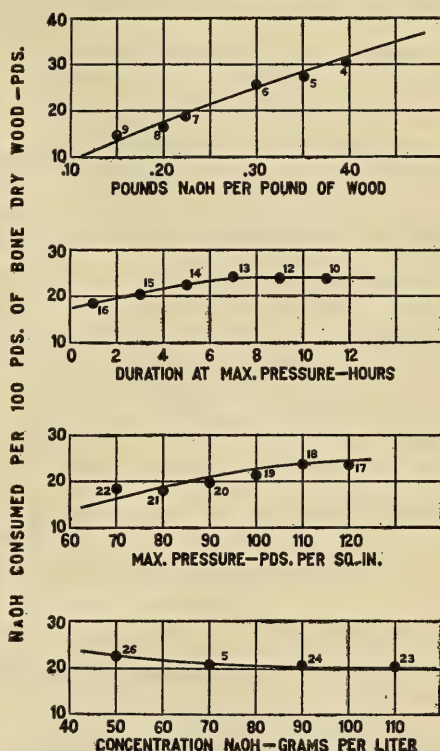


FIG. 13.—Effects of cooking conditions on the amount of caustic soda consumed.

¹ For the effect of water alone, see Tauss's experiments, Table 1.

of consumption and subsequently decrease of percentage efficiency are indicated. While the possibility of error is not eliminated,¹ this result indicates the need for further investigation.

RELATION BETWEEN CAUSTIC SODA CONSUMED AND YIELDS.

For the purpose of further studying the cooking effects of the various conditions employed, yields of total crude pulps from all of the cooks were platted against amounts of caustic soda consumed per 100 pounds of wood charged (fig. 14). The average curve drawn through these points indicates a definite relation between yields and

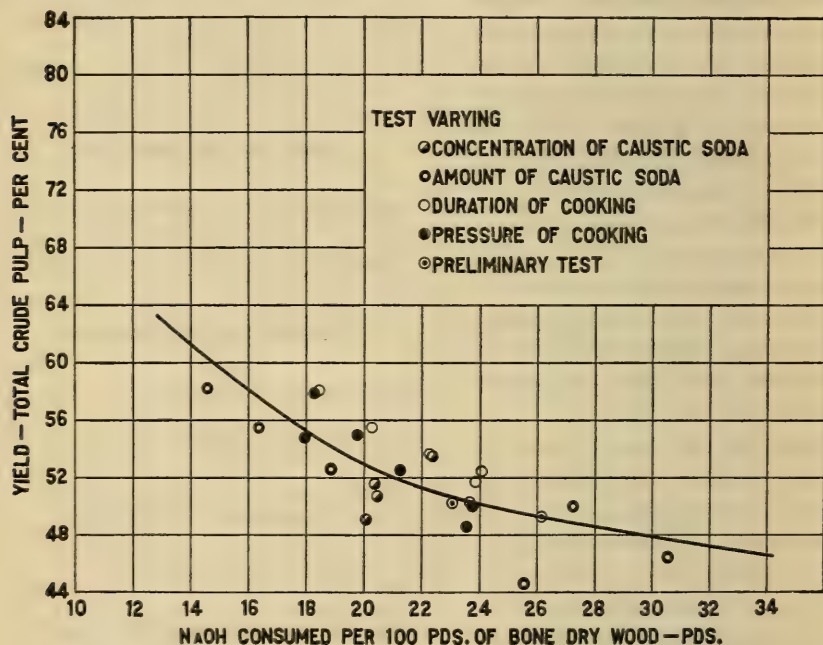


FIG. 14.—Relation between yields and amount of caustic soda consumed.

amounts of caustic soda consumed, regardless of the cooking conditions. However, even if it is assumed that the location of some of the points is due to experimental errors, the relation, as regards individual cooks, can be only an approximate one, since it has already been pointed out that in some of the tests increased cooking effects were obtained without any increase in the consumption of caustic soda. If the curve were produced for lower amounts of caustic soda, the yields would probably be somewhere between 80 and 100 per cent at zero consumption, since under these conditions cooking could still be effected by water alone.²

¹ The test data show a loss of digester liquor overflowing through the "top relief" for cooks 25 and 26 (that for cook 26 showing the greatest loss), and it is due to the platted points for these two cooks that the curves indicate greater consumption of caustic soda at the lower concentrations.

² See Tauss's experiments, Table I.

Since the completion of these experiments Mr. E. Sutermeister has published ¹ the results of some tests in which a small rotary autoclave and copper flasks were used as cooking vessels. Yields varying from 93 to 24 per cent and consumptions of caustic soda varying from 0 to 29 pounds per 100 pounds of wood were obtained,² giving a relation similar to that indicated by the curve in figure 14. However, in his experiments a greater reduction of yields was obtained per unit decrease in the caustic soda consumed, which is probably due to differences in test material, method of experimentation, and apparatus employed.

The actual consumption of caustic soda during cooking is a factor which is not given sufficient consideration in commercial practice, although it is one of considerable importance for an intelligent control of the cooking operations. By a careful study of the consumption, together with the other effects of the various cooking conditions, it is possible to determine the best operating conditions. That pulp mills do not ordinarily determine the consumption of caustic soda and the efficiency of its use is due to the length of time necessary for the analysis of the black liquors. While the method used in these experiments requires some time for carrying out the analysis, its occasional use in commercial operations would be of benefit in determining the conditions to be used in future cooks.³ If there were a rapid and accurate method of analysis such as is used in sulphite mill operations, it would assist in determining when the cooking had progressed far enough, at which time the digester could be blown. Production of undercooked or overcooked pulps would thus be avoided.

SEVERITY OF COOKING AS INDICATED BY MICROSCOPIC APPEARANCE OF FIBERS.

A good indication of the thoroughness or severity of cooking may be obtained by microscopic examinations of the pulp fibers.⁴ The effects of varying the cooking conditions are shown in figure 15; curve A represents the relative abundance of vessels in the pulps; curve B, the ray cells; curve C, the fiber bundles or shives; curve D, the prominence of the vessel markings; and curve E, the apparent strength of fiber walls. Since there are no absolute units for measuring these effects, the ordinates as shown for each curve represent arbitrary units ranging from 0 to 10. The photomicrographs in Plates II to VII, inclusive, present some of the more pronounced

¹ Paper, p. 15, No. 2, vol. 9, Sept. 25, 1912.

² In obtaining yields higher than 75 per cent the test material was treated at atmospheric pressure. Under this condition the cooking effect of water alone would have but little influence unless long durations of treatment were used.

³ The boiling of rags with caustic-soda solutions for the production of rag pulps is controlled in this manner.

⁴ For the normal appearance of fibers in the uncooked wood see Plates VIII and IX, as well as the discussion on p. 42.

effects.¹ While various gradations resulted,² the experimental pulps may be classified in the following three groups:

Overcooked pulps.—Severe digestion treatments resulted in “overcooked” pulps, examples of which are seen in Plates II and III. The walls of the fibers show a considerable degree of weakness, as indicated by their thin transparent appearance and by their much twisted and fractured condition. The relative number of vessels present in the pulp is low as compared with the normal number present in the wood, and the pits and other markings on them are only dimly visible. Many of the vessels remaining are

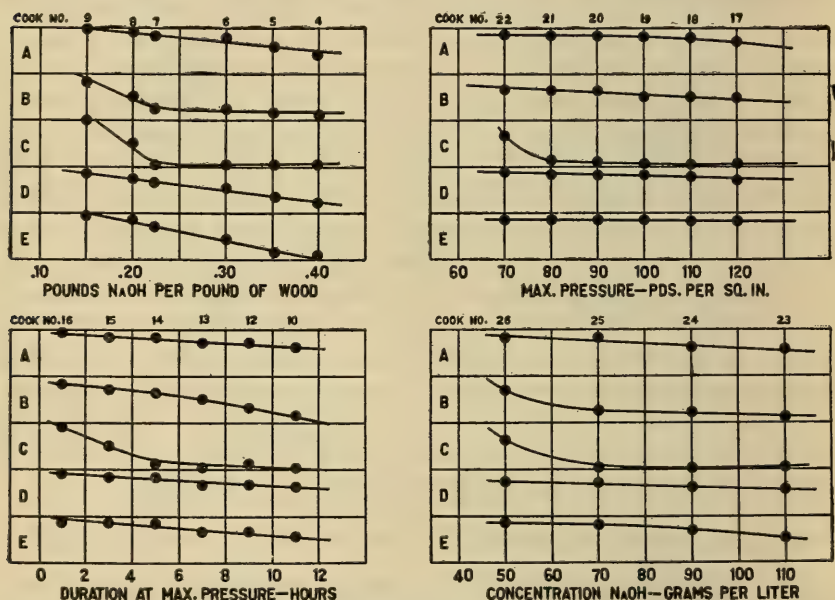


FIG. 15.—Effects of cooking conditions on pulp fibers. A, abundance of wood vessels; B, ray cells; C, fiber bundles, or shives; D, prominence of vessel markings; and E, apparent strength of fiber walls.

ragged and partly disintegrated; and the pulp, for the most part, is also characterized by an absence of the comparatively thin-walled, delicate ray cells. Fiber bundles also are absent, since these are made up of fibers bound together by groups of the brick-shaped ray or parenchyma cell. The indistinctness of the vessels and fibers is due chiefly to the removal of the ligneous infiltrations of the cell walls, in consequence of which the elements developed very little color from the particular stain used in making the microscopic mounts.

Well-cooked pulps.—Pulps produced under less severe conditions are made up of stronger fibers, such as shown in Plates IV and V.

¹ The remarks following the title of each plate and the discussion in the text are not based on the fields shown in the photomicrographs alone.

² The photomicrographs, in the order of their sequence, show gradations of severity of cooking.

The milder treatments are apparent in the increasing number of ray cells and vessels, the latter being well preserved and showing their markings quite clearly. The fibers are twisted or broken to only a small extent, and yet are so well separated that there are no fiber bundles.

Undercooked pulps.—Plates VI and VII illustrate the characteristics of undercooked pulps, and show plainly the mildness of the digestion treatments employed in their production. Well-preserved vessels with sharply defined markings are clearly visible, ray cells are numerous, and the walls of the fibers are less dissolved away than in the more thoroughly cooked pulps. Coincident with these characteristics there are also present many fiber bundles or shives, noticeable even when the microscopic slides are examined with the naked eye. Undercooked fibers develop a deep color from the particular stain used in mounting, and on this account appear very distinct.

Of the several groups of tests, the one varying the amounts of caustic soda per pound of wood resulted in the greatest range of severity of cooking as determined by the microscopic appearance of the pulp fibers. A small amount of chemical resulted in an undercooked pulp. With increases in the amount the strength of cell walls gradually decreased, the wood vessels suffered gradual destruction, and their markings were dimmed. The ray cells and fiber bundles disappeared soon after the point was reached where the maximum yield was attained. The higher amounts of caustic gave the overcooked effects.

For varying durations of cooking the effect was practically the same, and undercooked pulps were obtained at the shortest duration used. However, the highest durations employed did not give as severely cooked pulps as were obtained with large amounts of chemical. While all of the tests varying the cooking pressures resulted in fairly well cooked pulps, there was a tendency toward undercooking at the lowest pressure used. The tests varying the initial concentrations also resulted in well-cooked pulps, except for the highest concentration, where a slight overcooking effect was observed.

INFLUENCE OF COOKING CONDITIONS ON COST.

While it is not feasible from the data at hand to discuss all cost factors affecting the commercial production of pulps, the more direct effects of the cooking conditions employed can be shown. The actual effects on the cost of production, of course, depend upon various other operating conditions at any particular mill, but the general trend of the effects is the same, irrespective of local conditions.

TIME.

Shorter durations of cooking result in more efficient use of the digesting apparatus; more cooks can be made per day or per week,

and, as has been shown, yields of pulp per unit of wood are also increased, and consequently more pulp is secured per cook. The greater plant capacity thus obtained would result in a proportionate decrease of operating costs per ton of pulp.

Figure 16 shows the production of pulp per 24 hours continuous operation for each 100 pounds of wood capacity of digester as influenced by various durations of cooking. The curve was derived from the experimental data, assuming a one-hour period for blowing the digester after completing a cook and for charging the next cook, and

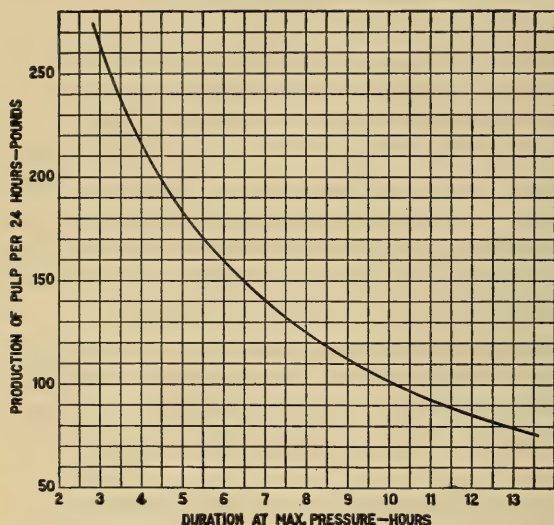


FIG. 16.—Effect of duration of cooking on production in 24 hours.

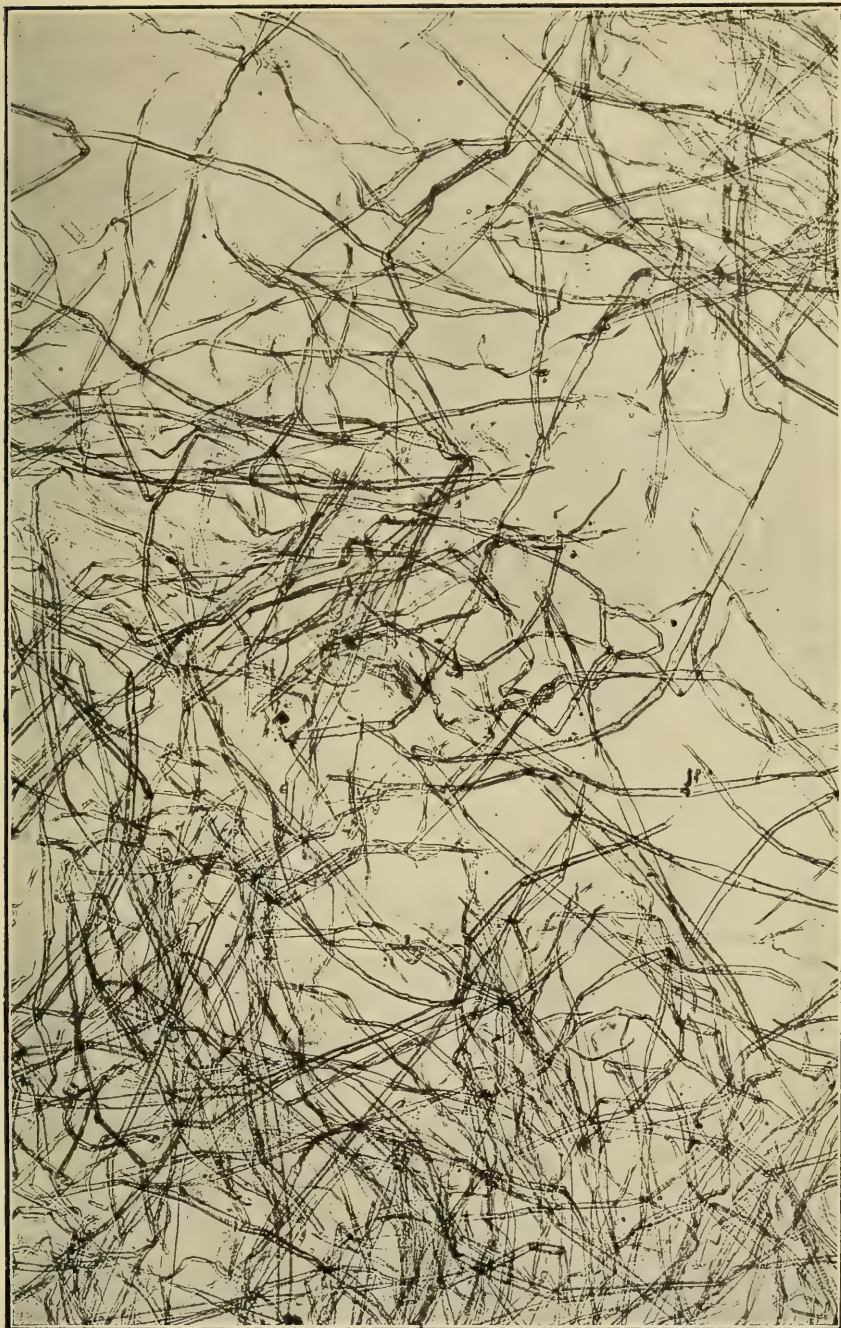
output 156 per cent. If the time allowed for blowing and charging the digesters and for raising the digester pressure is decreased, the increase in the daily output will be even more pronounced as the duration of cooking is shortened.

STEAM CONSUMPTION.

While the consumption of steam varies with the duration of cooking, it is influenced also by the pressure maintained in the digester and more by the relative volumes of the liquor charge. Under the testing conditions employed, the volume of liquor varied both with the amount of caustic soda charged (the concentration being constant) and with the concentration (the amount of chemical being constant). Since the heating was accomplished by steam blown directly into the digester, a measure of the amount of steam used is afforded by the increase in the volume of liquor during cooking.¹ The effects of the

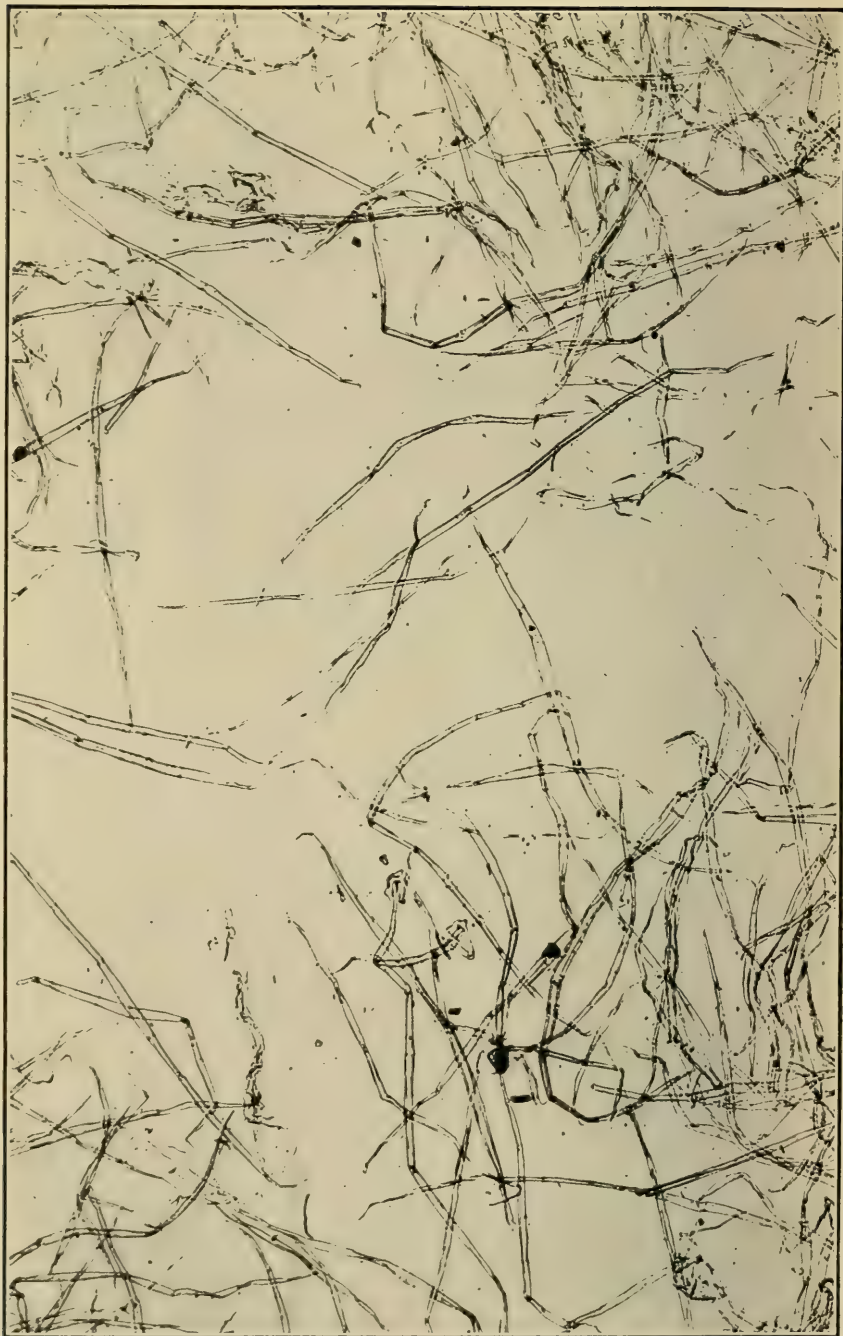
¹ The steam used was not perfectly dry, containing a small amount of moisture or "priming." However, as the steam was of approximately the same moisture content for all tests, the "condensation" was proportional to the amount of steam used.

a similar period for attaining maximum cooking pressure. Thus, for a three-hour period at maximum pressure, the total time between the charging of two consecutive cooks is five hours. Computation shows that decreasing the duration at maximum pressure from eight to five hours increases the daily output 48 per cent, while a decrease from ten to three hours increases the



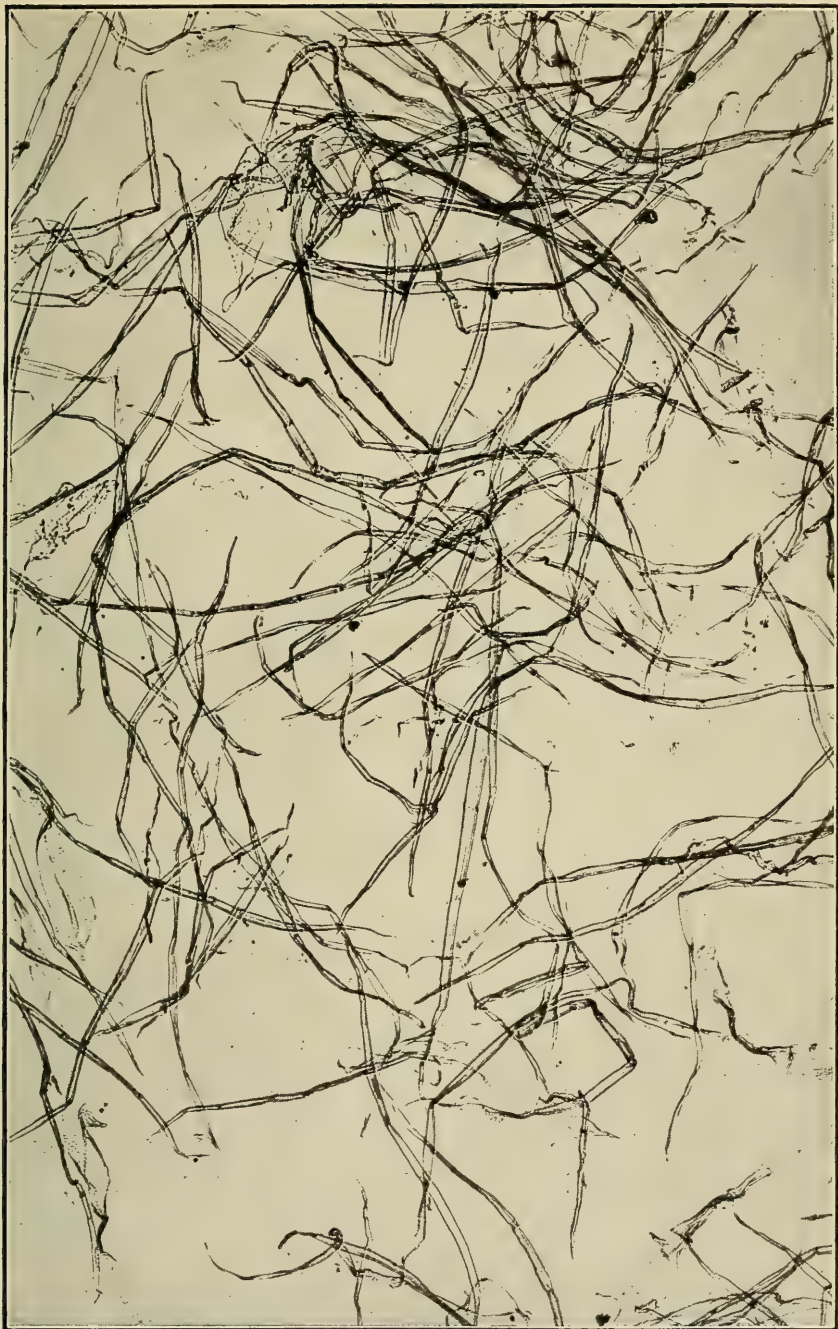
FIBERS OF AN OVER-COOKED PULP PRODUCED WITH A LARGE AMOUNT OF CAUSTIC SODA. (COOK 4.) MAGNIFIED 65 DIAMETERS.

Partial disintegration has taken place. The fibers are fragmentary and contorted with rather weak cell walls. The vessels with barely visible markings are on the point of being eliminated.



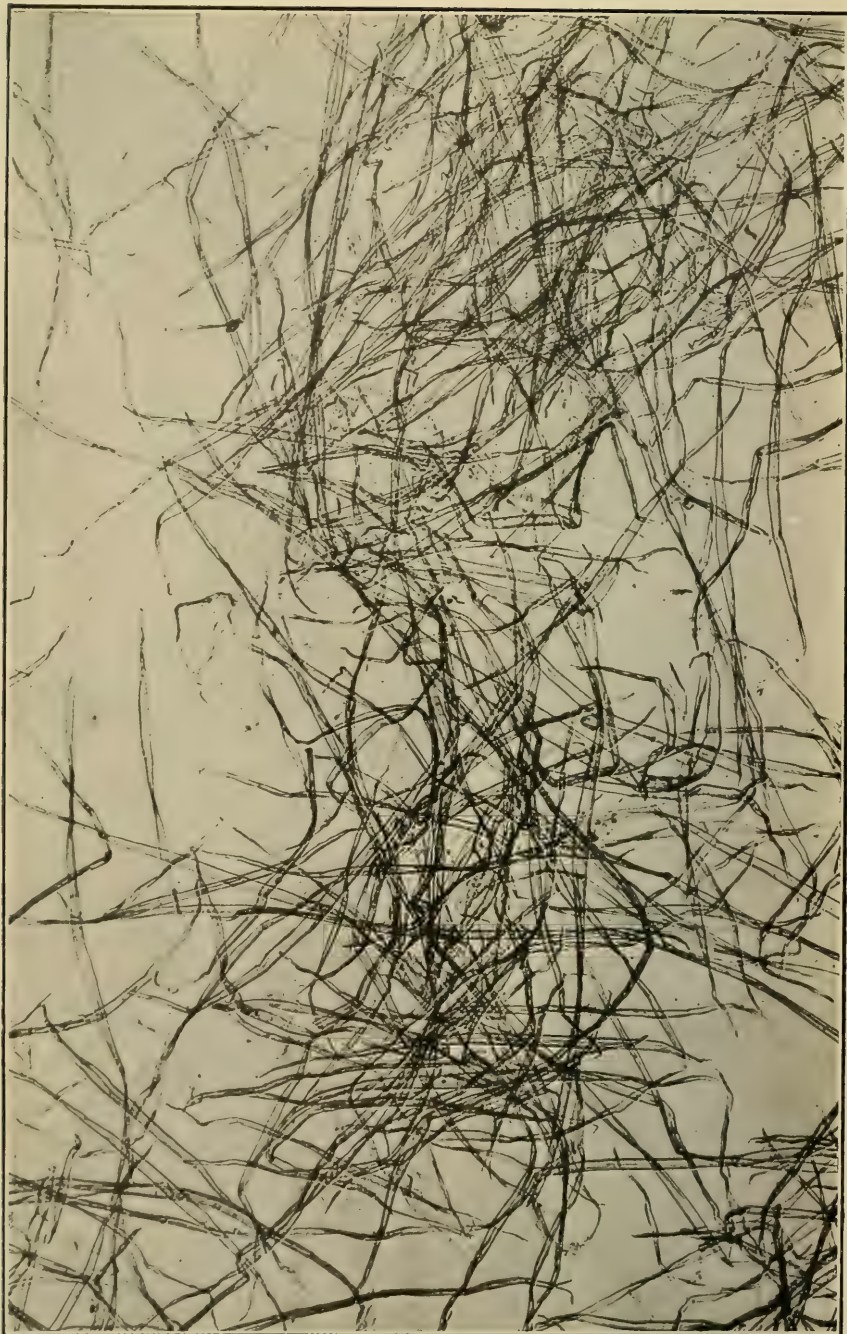
FIBERS OF AN OVER-COOKED PULP PRODUCED WITH A HIGH CONCENTRATION OF CAUSTIC SODA. (COOK 23.) MAGNIFIED 65 DIAMETERS.

The fibers are somewhat fragmentary.



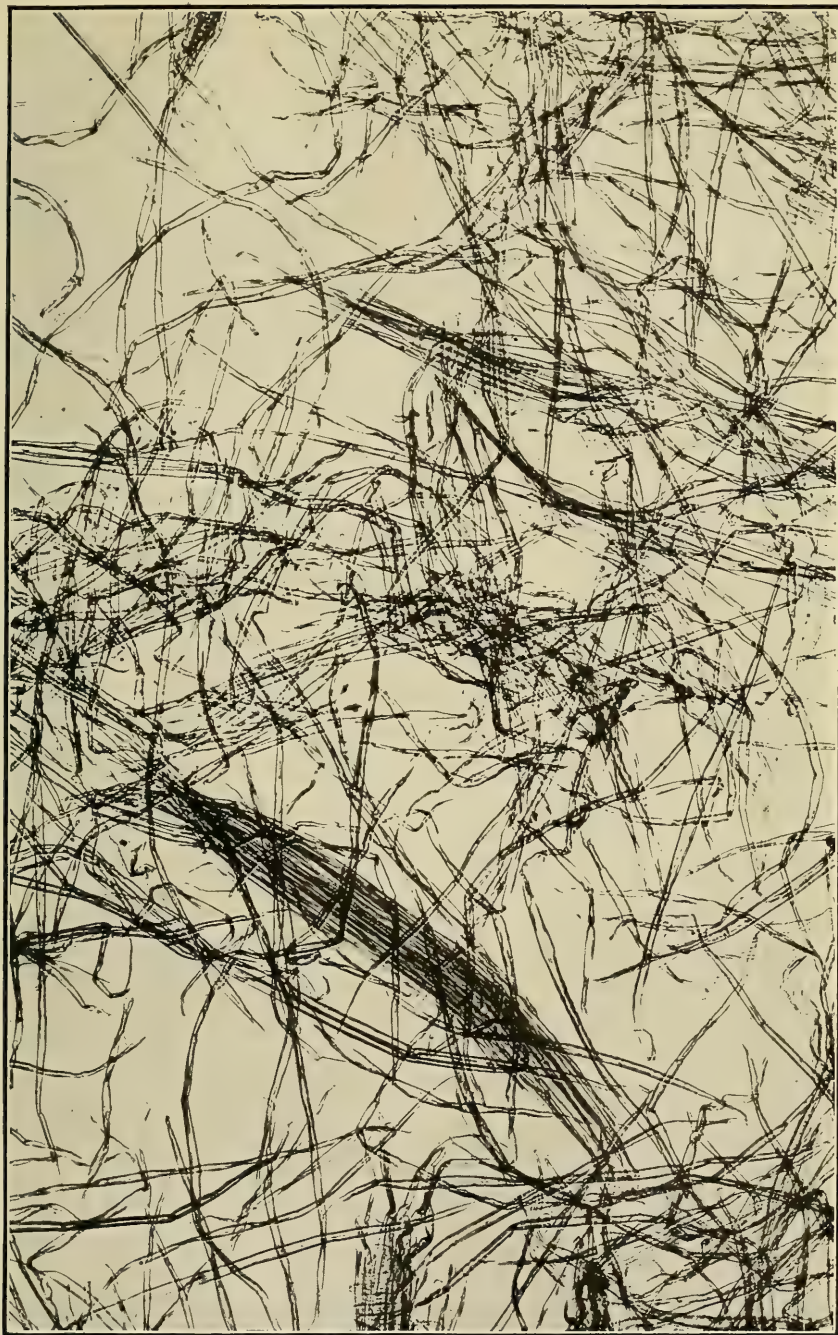
FIBERS OF A WELL-COOKED PULP PRODUCED WITH A MEDIUM AMOUNT OF CAUSTIC SODA. (COOK 7.) MAGNIFIED 65 DIAMETERS.

This is a pulp of average good quality. Vessels are well defined.



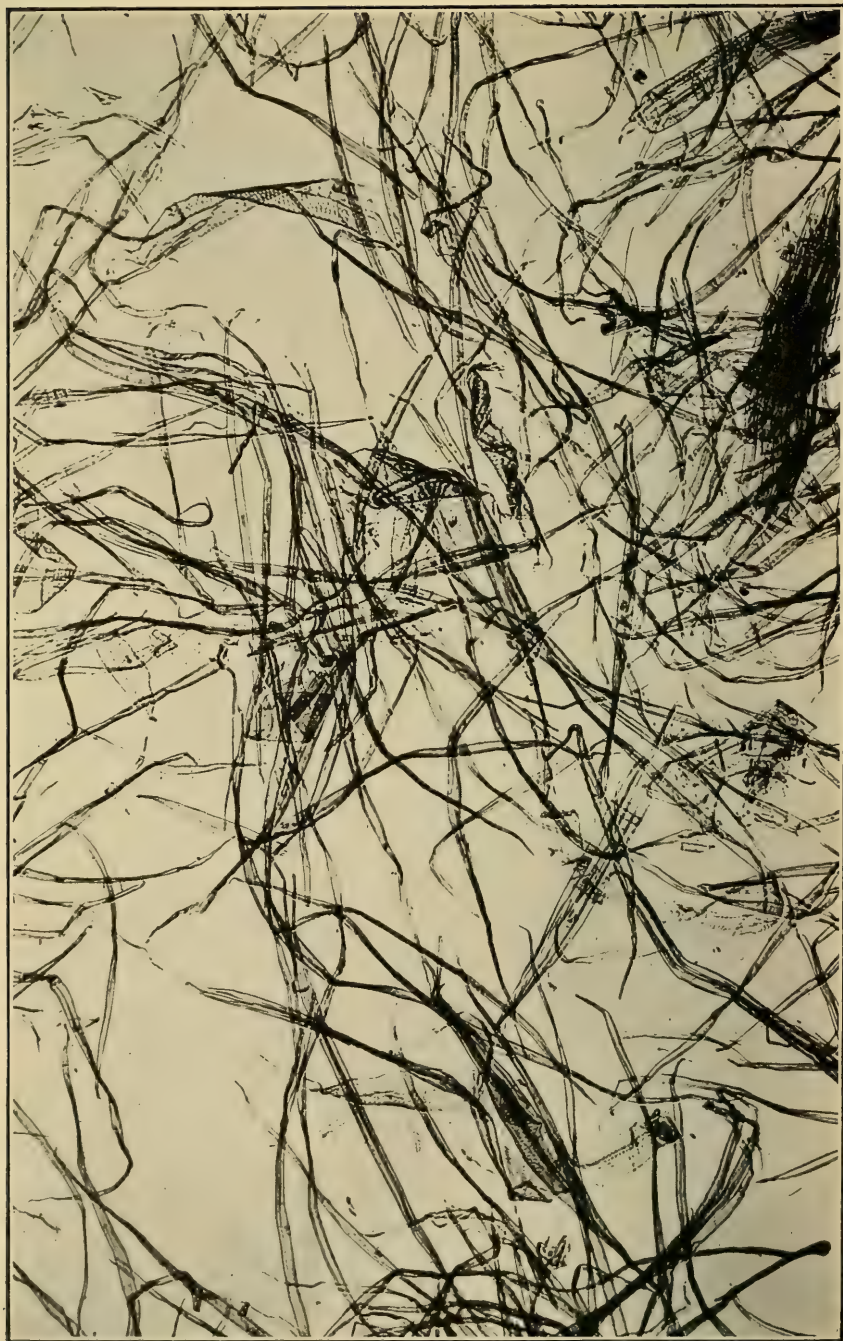
FIBERS OF A WELL-COOKED PULP PRODUCED WITH A HIGH PRESSURE OF COOKING.
(COOK 17.) MAGNIFIED 65 DIAMETERS.

This is a strong, well-separated pulp.



FIBERS OF AN UNDER-COOKED PULP PRODUCED WITH A SHORT DURATION OF COOKING.
(COOK 16.) MAGNIFIED 65 DIAMETERS.

Many shives, consisting of two or more unseparated fibers which parallel each other, are present.



FIBERS OF AN UNDER-COOKED PULP PRODUCED WITH A SMALL AMOUNT OF CAUSTIC SODA. (COOK 9.) MAGNIFIED 65 DIAMETERS.

Note the vessels with well-defined markings and the ray cells holding together a group of fibers constituting a shive.

cooking conditions on the resultant condensations are shown in figure 17. Curves showing the initial volumes of digester liquors for two of the groups of tests are also included in the same figure.

In the tests employing various proportions of caustic soda, the amount of liquor at the start of cook varied directly with the amount of chemical, as shown by the straight-line curve. The condensation also increased rapidly as the amounts were increased. The downward turn in the heavy-line curve for the higher proportions of caustic is caused by the digester becoming filled and overflowing through the top relief during the final stages of cooking. However, the dotted

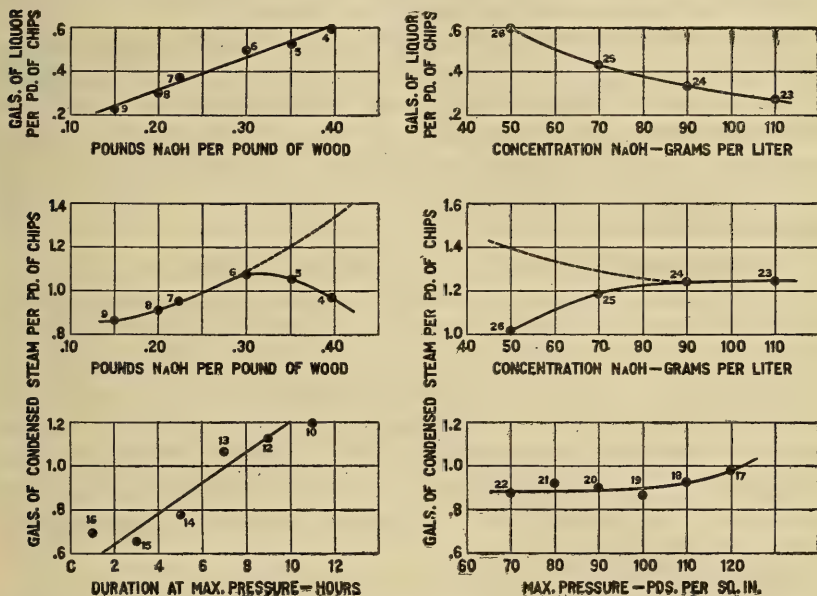


FIG. 17.—Effects of cooking conditions on initial volume of digester liquors and on condensation of steam.

line shows the corrected curve, taking the overflow into consideration. The rapid increase in the condensation is a natural consequence of increasing the amount of cooking liquor, which has a high specific heat.

In the tests employing various cooking periods the main influence on steam consumption was the heat lost by radiation, since the initial volumes of digester liquors were constant. The curve in figure 17 representing this effect has been drawn as a straight line to show only the general trend. It will be observed, however, that the platted points occur in two distinct groups. That the reaction between wood and caustic soda is of an exothermic or heat-generating nature may partly explain this arrangement. In the one group, representing the cooks of longer duration, the cooking reaction was

practically completed before the end of the cooking period (see analogous curves in figs. 12 and 13). This would result in relatively higher amounts of condensation, since no heat of reaction would be generated during the later stages of cooking.¹ The same explanation could apply to the cooks made at the higher pressures.

The influence of higher cooking pressures on steam consumption results from the greater amount of steam required to heat the digester and its contents to the higher temperatures and the greater loss of heat by radiation at such temperatures. The initial volumes of cooking liquor did not vary. The condensation curve indicates that this effect was comparatively small in the tests.

Like the tests varying the amount of caustic soda, those varying the initial concentration influence the steam consumption principally by the amount of liquor in the charge, which varies as shown by the true hyperbolic curve in figure 17. Hence, increasing the initial concentration decreased the condensation, as shown by the corrected curve in figure 17, which takes into account the overflow of the digester in cooks 25 and 26.

In considering these results from a commercial standpoint it should be kept in mind that the experimental apparatus was comparatively small. On this account the heat or steam required for raising the temperature of the digester and for replacing heat lost by radiation per unit of digester capacity was far greater than would be experienced in mill operation. Hence, much less steam per pound of chips would be required in commercial operations than is shown by these curves. The effects of increased duration of cooking and increased pressures especially would be much less pronounced, since with these radiation is the more important factor.

Aside from the direct cost of steam, the condensation is of importance in another way. The tests have shown that decreased initial concentrations, other cooking conditions being constant, result in less severe cooking. It is to be expected that the decrease of concentration throughout the cooking period, due to condensation, also tends to minimize the cooking effects in a similar manner.²

The use of superheated steam in cooking, the installation of larger digesters, the insulation or lagging of digesters, and the use of the minimum volume of cooking liquors at the start of cook are means frequently employed by pulp mills to reduce the condensation.

¹ The condensation curve (liquor in digester—gallons) in fig. 3, which is typical for most of the individual cooks in these experiments, also shows a greater rate of condensation at the end of the cook than at earlier periods except during the first hour when the pressure was being increased. This can be accounted for only by the fact that heat, other than from the steam alone, was supplied to the digester during the earlier stages of cooking. As the cooking reaction is most vigorous at the beginning, it seems probable that the heat supplied was heat of reaction.

² It is evident that the effects obtained in the tests varying the initial concentrations are much less pronounced than would have been the case if the diluting effect of condensation had been absent. The autoclave tests, for which data are given in Table 15, afford fairly conclusive proof of this.

CHEMICALS PER TON OF PULP.

The chemicals directly employed in the manufacture of soda pulp affect cost of production, in that the full amount of alkali charged to the digester can not be recovered, while the bleaching powder after being used is of no further value. The curves in figures 18 and 19, expressing the effects of the cooking conditions on the amounts of chemicals employed per ton of air-dry, bleached pulp, were derived from the experimental data as explained on page 48, appendix. The amounts shown are less than those generally employed in commercial practice, for several reasons: (1) The yields of pulp are higher; (2) the losses on bleaching are less; (3) the amounts of chemical charged per pound of wood are less; and (4) the amounts of bleach required are less. Whether or not pulp mills can duplicate or approach these results, the general trend of the curves would not be affected.

SODA ASH.

The amounts of caustic soda and sodium carbonate charged to the digester in the several groups of tests have been calculated to show the equivalent amounts of commercial soda ash (58 per cent Na_2O) per ton of bleached pulp produced. (Fig. 18.) Increasing the amounts of

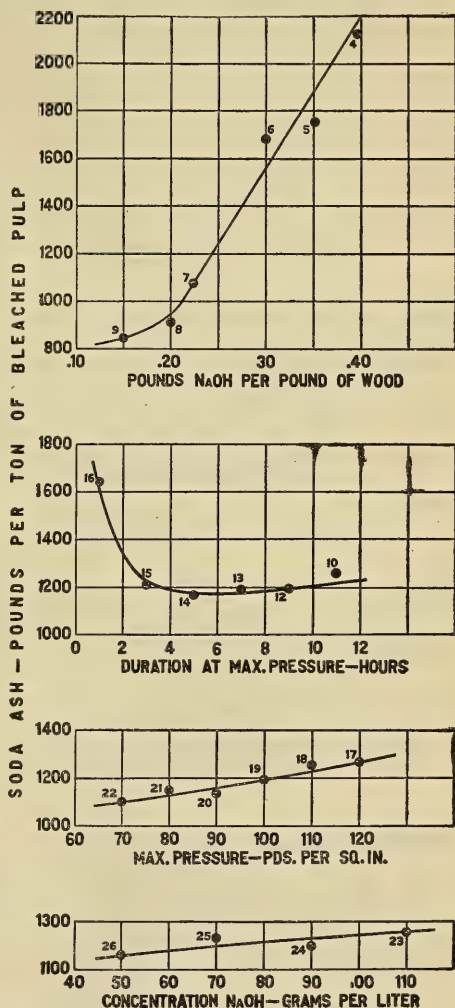


FIG. 18.—Effects of cooking conditions on amount of soda ash employed per ton of pulp.

caustic soda charged per pound of wood obviously results in increasing amounts of soda ash per ton of pulp, and the decreased yields of pulp resulting from the more thorough cooking make the effect more pronounced. A bend is found in the curve at the point of maximum yield, since for amounts of caustic below this point the yields decrease rapidly and their influence on the amount of soda ash employed per ton of pulp becomes more apparent.

When varying the durations and the pressures of cooking and the initial concentrations, the amounts of soda ash per ton of pulp were affected by yields alone, and the minimum amount is employed under conditions which give the maximum yields. Increased durations,

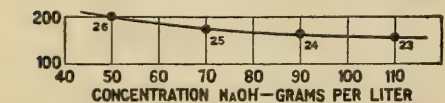
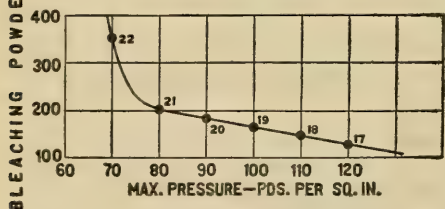
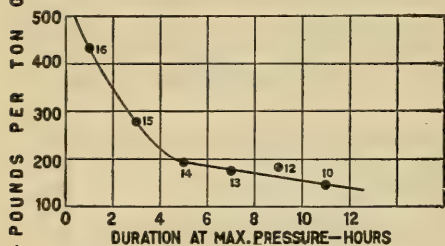
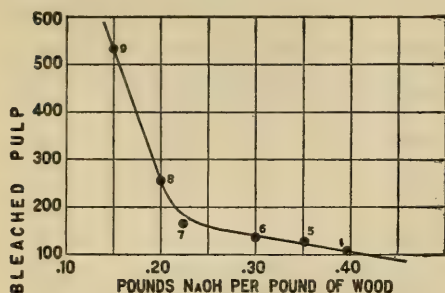


FIG. 19.—Effects of cooking conditions on amount of bleaching powder employed per ton of pulp.

percent available chlorine, and losses in making the bleaching solutions are disregarded.

COMBINED COST OF WOOD AND CHEMICALS PER TON OF PULP.

The curves in figure 20 show costs for certain items in producing a ton of bleached pulp (2,000 pounds air-dry basis) as influenced by variations in the cooking conditions. Curves marked A represent cost of wood alone; curves B, cost of wood and soda ash; and curves C,

pressures, and concentrations afford decreased yields, and the amount of soda ash per ton of pulp consequently is increased. The plotted point for cook 10 is not on the curve, due to the initial digester liquors for this cook having had about 3 per cent lower causticity than the other cooks in this group of tests. Lower causticities involve the use of a greater amount of soda ash for the same amount of caustic soda.

BLEACHING POWDER.

The curves in figure 19 show that increasing the amounts and concentrations of caustic soda and the durations and pressures of cooking result in all cases in decreasing the amounts of bleaching powder consumed.

Yields do not influence the calculations, since the consumption per ton of bleached pulp depends on the per cent of bleach required and the bleaching losses. The ordinates for the curves represent bleaching powder of 35 per

cost of wood, soda ash, and bleaching powder. The vertical distances between curves A and B represent cost of soda ash alone, and those between curves B and C represent cost of bleaching powder alone.

The cost values were obtained by calculations from the amounts of wood, soda ash, and bleaching powder consumed, based on the experimental results.¹ A 90 per cent recovery of the cooking chemicals charged to the digester was assumed in determining the amounts

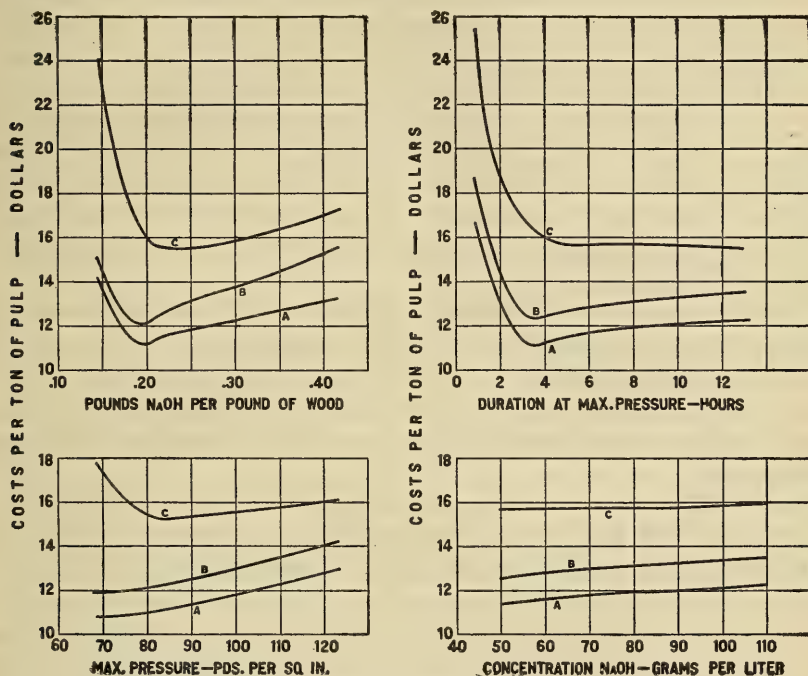


FIG. 20.—Effects of cooking conditions on cost items per ton of pulp. A, wood; B, wood and soda ash; and C, wood, soda ash, and bleaching powder.

of soda ash consumed or lost per ton of pulp. The basic units for costs are assumed average values as follows:

Wood, \$9 per solid cord (100 cu. ft.); soda ash (58 per cent Na_2O), \$1 per 100 pounds; bleaching powder (35 per cent available chlorine), \$1.55 per 100 pounds.² The bone-dry weight of aspen wood is taken as 26.68 pounds per cubic foot of clear wood, green volume.

¹ These amounts were calculated by interpolating from the yield curves (fig. 4), the loss on bleaching curves (fig. 10), and the curves for soda ash and bleaching powder employed per ton of pulp (figs. 18 and 19), and not from actual test data. On this account platted points have been omitted.

² Reasonable maximum, average, and minimum values for a "solid cord" of aspen f. o. b. mill are \$11, \$9, and \$6, as determined from statistical reports received from a number of mills. Correspondence with pulp manufacturers brought the information that reasonable maximum, average, and minimum unit costs as defined above may be assumed with a fair degree of accuracy as follows: For soda ash, \$1.20, \$1, and \$0.85; for bleaching powder, \$2.05, \$1.55, and \$1.10. These values do not depend upon market fluctuations alone, but vary through the range given, due largely to differences in freight charges for mills in different localities. The actual selling price of "58 per cent" soda ash is 10/48 greater than the manufacturer's or market quotations, since the latter are based on the old standard of "48 per cent" soda ash.

With increasing amounts of caustic soda in the digester charges the cost due to all three factors is decreased until the point of maximum yield of good pulp is attained, after which the total costs increase, due to the increasing amounts of wood and of soda ash consumed. The decreasing cost of bleaching powder only partially offsets the increase due to the other two factors.

With increasing durations the effect is practically the same, so far as wood alone is concerned, except that the increase in its cost for higher durations is not so pronounced as with increasing the amounts of caustic soda. The soda-ash costs alone are practically constant, and hence increase the wood costs by a constant amount. However, as the durations increase, the bleaching-powder costs decreased sufficiently to overcome the effect of increasing wood costs. After the minimum duration for successful cooking (as determined by yields) has been exceeded, the decrease in total cost is very small, and would not be sufficient to offset increased costs incident to the time element discussed previously.

For variations in the pressures of cooking, the influence of bleaching-powder costs is especially marked. The minimum costs due to wood and soda ash result from the use of the lower pressures. When bleaching is considered, the minimum cost is obtained by using medium pressures, although the increases for the higher pressures are very small.

Combined costs for the three factors are practically unaffected by variations in the initial concentrations, but if bleaching is omitted the costs of wood and soda ash are larger with the higher concentrations.

All of the diagrams show that of the three cost factors considered, wood is of the most importance and that bleaching powder is more influential than soda ash in determining total costs. Increases in costs of wood and soda ash with increasing severity of cooking are, in all cases, offset, to a greater or less extent, by decreases in bleaching-powder costs. If maximum or minimum values ¹ had been used for either wood, soda ash, or bleaching powder, instead of the average value, or if a different percentage recovery for the soda ash had been assumed, the general effects would not be changed, although they might become more or less pronounced.

SUMMARY. ²

(1) The amount of caustic soda per pound of wood, the duration of cooking, the pressure or temperature of cooking, and the concentration of the cooking chemicals employed in the production of soda

¹ See footnote, p. 37.

² The more general statements in the summary will be found to coincide in a greater or less degree with previously existing opinions, a fact not surprising when it is remembered that the soda process has been carried on for half a century. On the other hand, satisfactory evidence and data substantiating these opinions have not been available. The present investigation affords such information, as well as a basis for more specific conclusions.

pulp influence the yield and properties of the pulp by influencing the severity of the cooking reactions.

(2) Severity of cooking is an effect mainly of the amount of caustic soda consumed per unit of wood. Increasing the amount or concentration of the chemical or the pressure of cooking produces a quicker reaction and hence one more complete in a given length of time. Increasing the duration results in a more complete reaction because of the longer time allowed for the available caustic soda to be consumed.

(3) Greater severity of cooking is accompanied by a decrease in the yield of crude pulp, and usually of screened pulp. If screenings are present in considerable quantity (due to incomplete cooking), more thorough cooking increases the yield of screened pulp.

(4) The properties of the pulp are influenced by greater severity of cooking as follows:

- (a) Shives are decreased in number or eliminated.
- (b) Bleaching is rendered more easy and the loss on bleaching becomes less.
- (c) The strength may either decrease or increase, depending upon which cooking condition is varied and the degree of variation.
- (d) The color of the unbleached pulp becomes lighter within certain limits, beyond which it may, under certain conditions, become darker.

(5) A good indication of the severity of cooking is the appearance of the individual fibers when examined under the microscope.

(6) The decreased yields resulting from more severe cooking result in a greater cost of wood and soda ash per ton of pulp. As a rule, the smaller cost of bleaching powder incident to the more easily bleached pulp produced by thorough cooking only partially offsets the greater cost of wood and soda ash.

(7) While the amount of bleach required decreases with increasing severity of cooking, a point is soon reached where the decrease in bleach required is not commensurate with the decrease in yields.

(8) Increasing the initial amount of digester liquor increases the condensation and steam consumption (and hence the cost) because of the greater volume to be heated; increasing either the duration or pressure has a similar effect because of the greater losses of heat by radiation.

(9) Yields (bone-dry basis) of well-separated unbleached pulps as high as 56 or 58 pounds per 100 pounds of wood can be obtained from aspen if the wood is of the best quality. Yields of from 54 to 55 per cent were obtained which required only from 10 to 11 per cent of bleach. The variation in yields obtained by changing the cooking conditions was from 46 to 58 pounds per 100 pounds of wood charged, or about 26 per cent based on the lowest yield.

(10) Minimum total durations of from 3 to 4 hours may be successfully applied to the cooking of aspen for bleaching pulps, provided the other cooking conditions are properly maintained.

(11) Aspen may be successfully cooked with a minimum of from 20 to 25 pounds of caustic soda charged per 100 pounds of wood. The amount of this chemical actually consumed in the production of well-cooked bleaching pulps varies from 18 to 24 pounds per 100 pounds of wood.

PRACTICAL VALUE OF RESULTS.

The experiments discussed in this bulletin have shown in detail the effects of certain cooking conditions on the yields and properties of the resultant pulp, on the efficiency of the cooking chemicals, and on various items affecting costs of production. From a study of these results it should be possible for a mill operator so to regulate the cooking process as to secure the largest possible yield of pulp of the desired quality at a minimum cost for chemicals, fuel, labor, and overhead charges in so far as the operation is affected by the cooking conditions considered.

The clear, sound wood used in the experiments afforded yields of good pulp from 10 to 25 per cent higher than the better run of the yields reported by pulp mills. Moreover, some of these experimental yields were obtained with shorter cooking periods and less chemicals than are employed commercially. Although the laboratory results may not be equaled in mill practice, the possibility of greatly increased efficiency in the process of converting wood into soda pulp is indicated.

APPENDIX.

ASPEN AS A RAW MATERIAL FOR PAPER PULP.

DISTRIBUTION AND CHARACTERISTICS OF THE TREE.¹

Aspen (*Populus tremuloides* Michx.), or quaking aspen, as it is sometimes called, is one of the most widely distributed and best-known American trees. Together with the closely related European species, *Populus tremula* Linn., from which paper pulp of excellent quality is also prepared, it encircles almost the entire globe. In America aspen extends from Labrador to Alaska and southward to Tennessee and Arizona. Yet it occurs scatteringly, and pure stands of any extent are comparatively rare. For this reason it is not possible to give even approximately the present total stand. In the western forests, notably those of Utah and western Colorado, there are vast quantities which will doubtless be an important source of future supply. In the past New England furnished most of the aspen pulpwood, and although the supply there is badly depleted, considerable quantities yet remain in certain regions, notably in northern Maine.²

Aspen is a very rapid grower and quickly covers burned or logged-over lands. However, it is comparatively short-lived, and the larger trees suffer severely from fire, windshake, insects, and fungi. In fact, aspen is defective from decay to a greater extent than any other commonly used pulpwood, except perhaps balsam fir. The trees ordinarily used for pulpwood are from 5 to 14 inches in diameter. If grown in close stands, the trunks are fairly free from knots and limbs. Logging is comparatively easy.

Aspen wood after cutting is also susceptible to fungous attack unless kept very dry. It is particularly perishable in contact with the soil. The ability of the wood to season rapidly, especially after being barked, is of much advantage. Nevertheless, mills which store a year's supply or more in open yards undoubtedly have a large proportion of their older wood affected. The general opinion is that "old wood" produces inferior pulp and lower yields.

PROPERTIES AND STRUCTURE OF THE WOOD.

The wood of aspen is soft, light in weight, not strong, and close grained, but with numerous minute, open ducts. The medullary rays are very thin and hardly distinguishable with the naked eye. The color is light brown, the sapwood almost white and very thick, often representing 25 to 30 layers of annual growth. In the green or freshly seasoned material, however, the difference between heartwood and sapwood is in most cases scarcely appreciable. A cubic foot of air-dried wood usually weighs from 25 to 30 pounds.

¹ A more complete discussion of the silvical characteristics of aspen is given in Forest Service Bulletin 93, The Aspens; Their Growth and Management, by W. G. Weigle and E. H. Frothingham, 1911.

² Forest Service Bulletin 93, pp. 13 and 17, 1911.

Determinations¹ made on sound sticks of aspen varying from 8 to 10 inches in diameter showed about 62.8 per cent of cellulose. Müller, quoted by Clapperton,² gives the following analysis³ for the poplars:

	Per cent.
Cellulose.....	62.77
Resin.....	1.37
Aqueous extract.....	2.88
Water.....	12.10
Lignin.....	20.88
	100.00

Since bleached pulp is very nearly pure cellulose, the maximum yield obtainable could not be appreciably higher than 63 per cent.

Aspen wood is made up of three types of structural elements—fibers, vessels, and parenchymatous tissue. The latter comprises the medullary ray cells and the rather scantily developed parenchyma cells at the end of the year's growth. The structure is shown in Plates VIII and IX. In Plate VIII, figure 1, the long tubes running the length of the picture are the vessels; cross sections of the medullary rays can be seen scattered among the fibers as dark vertical "plates," one cell in width and several in height. The ray cells are characterized by exceedingly thin walls, and when the wood is cooked for pulp these cells readily dissolve. The vessels are more resistant to chemical attack than the parenchymatous tissue, and the fibers, because of their relatively thick walls, are least affected by the cooking process. It is also possible that the cellulose constituting the fiber walls is more resistant than the cellulose of the other elements. In Plate IX, figure 2, the middle lamella or intercellular substance appears as a black line between the adjacent walls of the elements. This is dissolved in the process of cooking for paper pulp.

Aspen fibers are comparatively short. Examples of long-fibered woods used in paper making are spruce, hemlock, and balsam fir, and of medium-length ones tulip tree, sweet gum, and cottonwood. The actual dimensions of aspen fibers vary a great deal with the tree and the part of the tree from which secured. Forest Service measurements⁴ of a large number of fibers of aspen wood showed a range of from about 0.5 to 1.6 mm. in length and an average length of 1.0 mm.⁵

PULPWOOD CONSUMED.

At the present time soda, sulphite, sulphate, and mechanical pulps are made from aspen and other poplars, but the soda process has always used these woods in by far the greater amounts, and they continue to form the chief pulpwood supply for this process. The other processes of pulp making have been applied to the poplars within recent years only, although it was known 20 or 30 years ago that they could be ground for mechanical pulp and could be reduced without difficulty by the sulphite process to an easy-bleaching pulp. The properties of the wood and the yields and qualities of the pulp made from it, combined with the proximity of an adequate supply and its relatively low cost, made this the best wood obtainable for the manufacture of soft, easy-bleaching soda pulp.

¹ Forest Service Bulletin 93, p. 7, 1911.

² Practical Papermaking, p. 43, 1907.

³ This analysis makes no mention of the ash. According to Sargent (Tenth U. S. Census Rept., Vol. IX) the ash in aspen varies from 0.31 to 0.76 per cent, with an average of 0.55 per cent, of the air-dry wood. See this report also for further data on the chemical composition and properties of aspen.

⁴ Forest Service Bulletin 93, p. 7, 1911.

⁵ One millimeter is equivalent to approximately one twenty-fifth of an inch.

TABLE 5.—Consumption of poplar pulpwood and of all pulpwoods in the United States for years 1899 and 1905 to 1910, inclusive.

Year and process.	Domestic poplar.	Imported poplar.	Total poplar.	All pulpwoods.	Ratio domestic poplar to total poplar.	Ratio total poplar to all pulpwoods.
1910. ¹	<i>Cords.</i>	<i>Cords.</i>	<i>Cords.</i>	<i>Cords.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Mechanical.....	11,613	1,834	13,447	1,180,598	86.4	1.1
Sulphite.....	² 703	.....	² 703	³ 2,257,881	100.0	.03
Soda.....	303,401	43,525	346,926	655,827	87.5	53.0
	315,717	45,359	361,076	4,094,306	87.4	8.8
1909. ¹						
Mechanical.....	17,905	3,025	20,930	1,246,121	85.6	1.7
Sulphite.....	2,930	.....	2,930	⁴ 2,183,984	100.0	.1
Soda.....	282,041	22,597	304,638	571,502	92.6	53.3
	302,876	25,622	328,498	4,001,607	92.2	8.2
1908. ¹						
Mechanical.....	16,734	2,168	18,902	1,117,428	88.0	1.7
Sulphite.....	3,734	3,023	6,757	1,739,282	55.3	.4
Soda.....	259,096	17,462	276,558	490,243	93.6	56.4
	279,564	22,653	302,217	3,346,953	92.5	9.0
1907. ¹						
Mechanical.....	16,903	2,620	19,523	1,361,302	86.5	1.4
Sulphite.....	1,536	.....	1,536	2,059,496	100.0	.1
Soda.....	333,703	17,178	350,881	541,862	95.0	64.7
	352,142	19,798	371,940	3,962,660	94.7	9.4
1906. ⁵						
Mechanical.....	10,475	2,129	12,604	1,197,780	82.8	1.1
Sulphite.....	.....	.....	.....	1,958,619	.....	.0
Soda.....	300,445	15,421	315,866	504,777	95.1	56.5
	310,920	17,550	328,470	3,661,176	94.6	9.0
1905. ⁶						
Mechanical.....	8,592	2,800	11,392	1,096,794	75.4	1.0
Sulphite.....	.....	.....	.....	1,630,393	.....	.0
Soda.....	290,583	20,083	310,666	464,936	93.5	66.8
	299,175	22,883	322,058	3,192,123	92.9	10.1
1899. ⁷						
Total.....	⁸ 236,820	⁸ 20,133	⁸ 256,953	1,986,310	92.3	12.9

¹ Bureau of the Census Circulars, Forest Products No. 1, Pulpwood Consumption (for respective years).² Includes 78 cords reduced by the sulphate process.³ Includes 10,188 cords reduced by the sulphate process.⁴ Includes 38,000 cords reduced by the sulphate process.⁵ Forest Service Circular 120, Consumption of Pulpwood in 1906.⁶ Forest Service Circular 44, Wood used for Pulp in 1905.⁷ Twelfth Census Bulletin 99, Manufactures: Paper and Pulp, Sept. 30, 1901.⁸ Used exclusively by the soda process.

TABLE 6.—*Cost of poplar pulpwood and of all pulpwoods at United States mills in 1907, 1908, and 1909.*¹

	Quantity.	Total cost.	Average cost per cord.
1909.			
Rough wood:	<i>Cords.</i>	<i>Dollars.</i>	<i>Dollars.</i>
Domestic poplar.....	13, 953	72, 555	5. 20
Imported poplar.....	2, 984	24, 469	8. 20
Total poplar.....	16, 937	97, 024	5. 72
All pulpwoods.....	2, 219, 083	17, 608, 736	7. 94
Peeled wood:			
Domestic poplar.....	288, 923	2, 337, 461	8. 09
Imported poplar.....	22, 638	179, 019	7. 91
Total poplar.....	311, 561	2, 516, 480	8. 07
All pulpwoods.....	1, 413, 997	12, 169, 393	8. 61
Rough and peeled wood:			
Domestic poplar.....	302, 876	2, 410, 016	7. 96
Imported poplar.....	25, 622	203, 488	7. 94
Total poplar.....	328, 498	2, 613, 504	7. 95
All pulpwoods.....	² 4, 001, 607	34, 477, 540	8. 62
1908.			
Domestic poplar.....	279, 564	2, 237, 631	8. 01
Imported poplar.....	22, 653	182, 143	8. 04
Total poplar.....	302, 217	2, 419, 774	8. 00
All pulpwoods.....	3, 346, 953	28, 047, 473	8. 38
1907.			
Domestic poplar.....	352, 142	2, 763, 889	7. 85
Imported poplar.....	19, 798	167, 039	8. 44
Total poplar.....	371, 940	2, 930, 928	7. 88
All pulpwoods.....	3, 962, 660	32, 360, 276	8. 17

¹ Bureau of the Census Circulars, Forest Products No. 1, Pulpwood Consumption (for respective years). Prices quoted are based on f. o. b. mill deliveries.

² Includes 368,527 cords of rossed wood at an average cost of \$12.75 per cord.

While there are no statistics of the consumption of aspen pulpwood alone, the Census figures ¹ for the consumption of "poplar" are of interest. The woods grouped under this name consist of several species of the true poplars, of which aspen is by far the most important, and doubtless include also a small amount of "yellow poplar" or tulip tree (*Liriodendron tulipifera* Linn.). The poplars collectively stand third in the amount cut for pulpwood, being exceeded only by spruce and hemlock. Table 5 shows the amount of poplar pulpwood used, by processes, in 1899 and each year from 1905 to 1910, inclusive. The cost of poplar per cord in 1907, 1908, and 1909 is shown in Table 6. The average cost per cord for poplar pulpwood did not change materially during the period 1907 to 1909, though the average cost per cord for all pulpwoods steadily advanced.

PAPER PULP FROM ASPEN.

CHARACTERISTICS AND PROPERTIES.

Aspen soda pulp, when unbleached and dry, is a very light brown or light reddish-brown much resembling ordinary blotting paper. While fairly tenacious, the pulps are usually very soft and bulky, whether bleached or unbleached. The softness of the pulp may be partly due to the fact that its natural resin content is normally very low (0.05 per cent) as compared with ordinary sulphite pulp (0.5 per cent). Aspen soda pulp is easily bleached to a good white color, though in some cases there may be a slight reddish tinge. For well-cooked pulp very low amounts of bleaching agents are required, and the loss on bleaching (from 6 to 10 per cent in commercial practice) is comparatively small. The following table by Griffin and Little ² affords a com-

¹ For statistics on the consumption of poplar pulpwood by Canadian mills, see bulletins 12, 26, and 30, of the Forestry Branch, Canadian Department of the Interior, 1909-1912.

² Chemistry of Papermaking, p. 280, 1894.

F

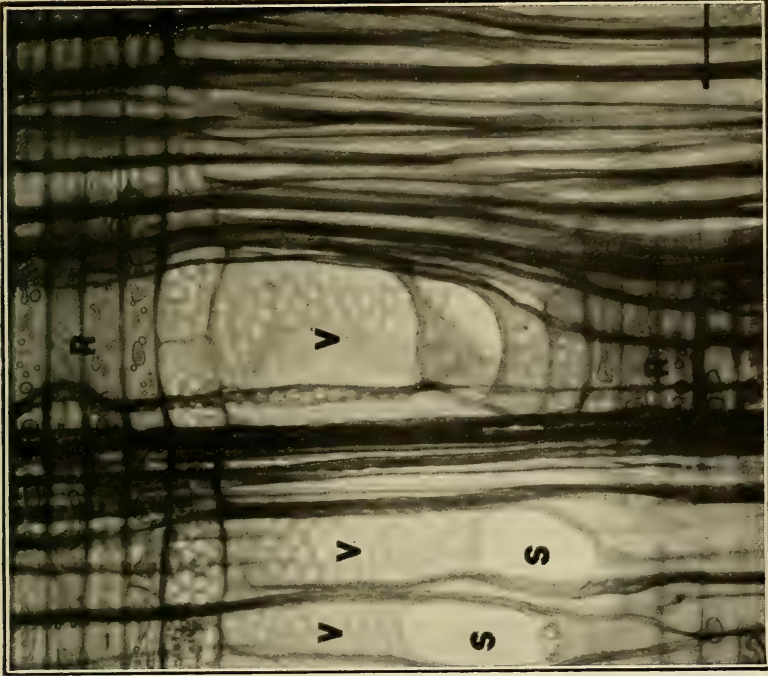


FIG. 2.—LONGITUDINAL RADIAL SECTION OF ASPEN. MAGNIFIED 250 DIAMETERS.
S, openings or pores in end walls of vessels; R, medullary rays; F, fibers; V, vessels.

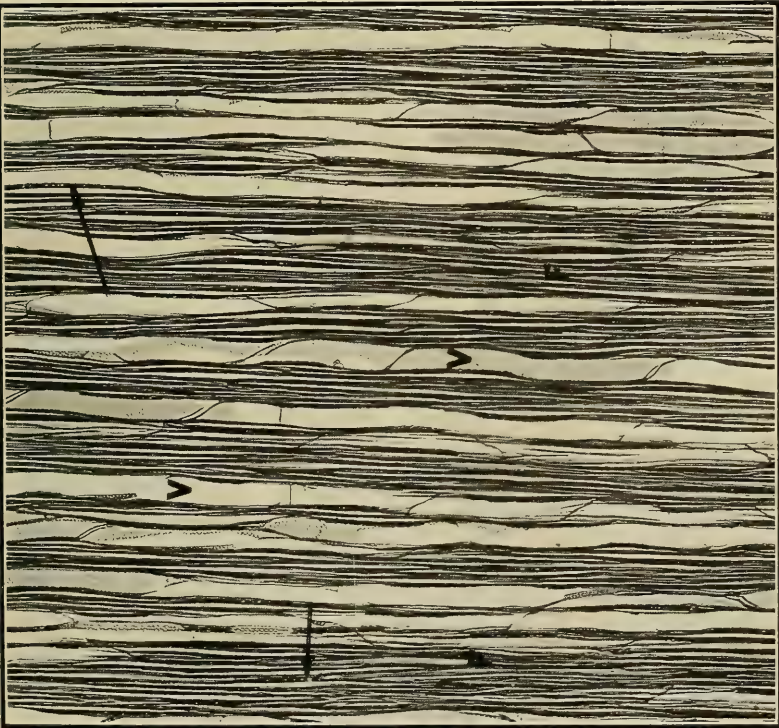


FIG. 1.—LONGITUDINAL TANGENTIAL SECTION OF ASPEN. MAGNIFIED 50 DIAMETERS.
F, fibers; V, vessels; arrows indicate medullary rays in vertical "plates."

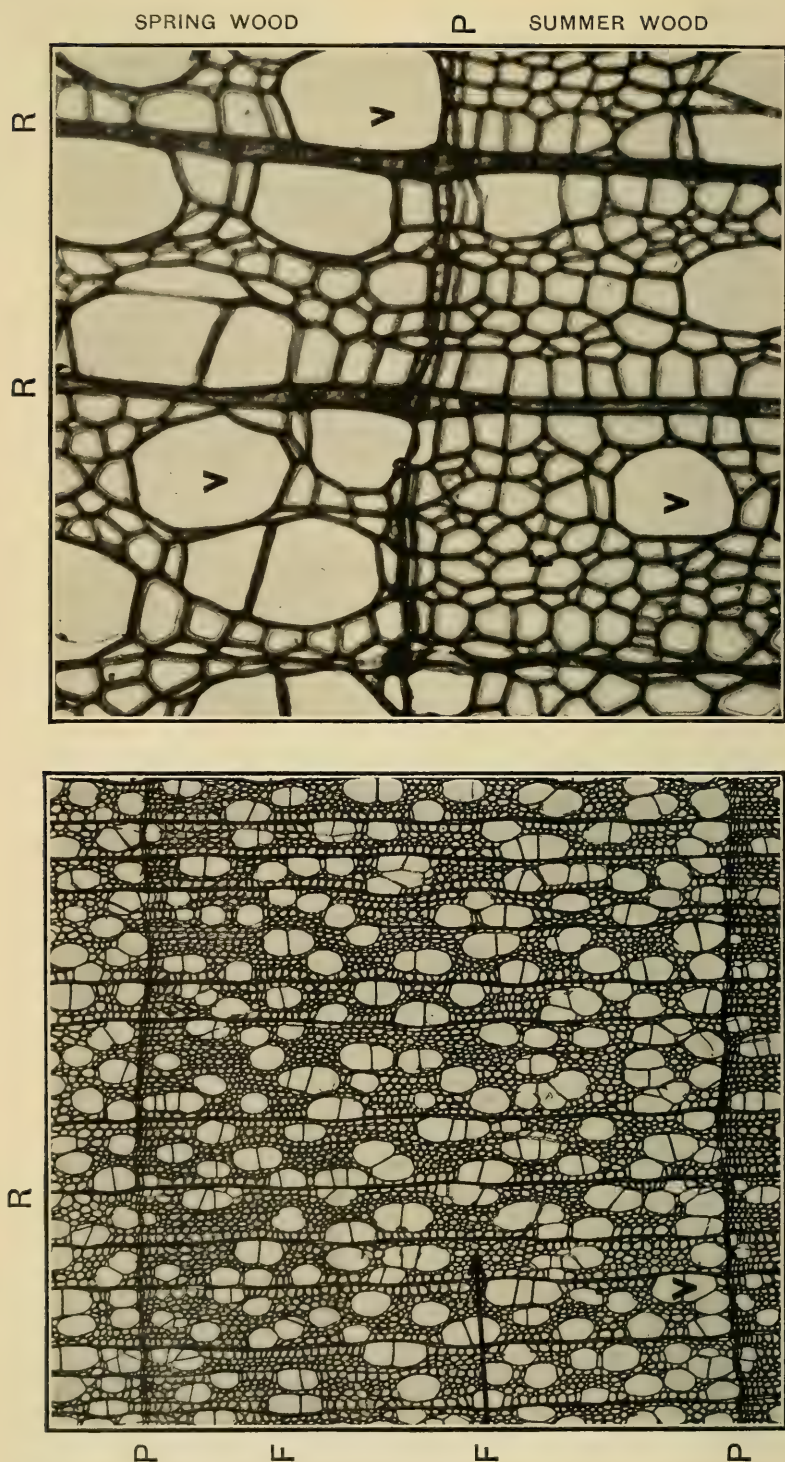


FIG. 1.—CROSS SECTION OF ASPEN. MAGNIFIED 50 DIAMETERS.

P, scantily developed parenchyma cells at end of year's growth; F, fibers; V, vessels; R, medullary rays.

FIG. 2.—CROSS SECTION OF ASPEN. MAGNIFIED 250 DIAMETERS.

R, medullary rays; V, vessels; P, scantily developed parenchyma cells at end of year's growth.

parison between the amounts of bleaching powder required for pulps from poplar (including aspen) and for other pulps:

TABLE 7.—*Amount of bleaching powder required for commercial pulps.*

Kind of pulp.	Bleaching powder per 100 pounds of pulp.
	<i>Pounds.</i>
Soda spruce.....	18-25
Soda poplar.....	12-15
Soda esparto.....	10-15
Sulphite spruce.....	15-25
Sulphite poplar.....	14-20

The individual fibers in aspen soda pulp are of the following dimensions:¹ Length, from 0.67 to 1.49 mm., averaging 0.99 mm.; breadth at the middle, from 0.01 to 0.03 mm., averaging 0.02 mm.; approximate thickness of cell walls, 0.002 mm.; ratio of length to breadth, 50:1. The fibers are slender, gradually tapering to needle-pointed ends. They are pliable and mostly curved, although many are nearly straight. While sometimes twisted and often swollen in nodes, with slight constrictions, they are never badly tangled or knotted. Aspen fibers tend to be more nearly circular in cross section than those from conifers. Other distinguishing characteristics are the medium length of the fibers and the presence, except in "overcooked" pulps, of remnants of the larger wood vessels and parenchymatous tissue. The vessel walls have closely packed bordered pits with hexagonal contour, and the inside walls are not marked with spiral thickenings, as is the case with some species. The vessel ends have open pores without gratings, which distinguishes aspen pulp from that of the tulip tree or yellow poplar sold in European markets under the name "Amerikanische Aspenzellulose."²

YIELDS.

The yields reported by a number of American soda-pulp mills operating on aspen and other woods are given in Table 8.

TABLE 8.—*Yields of soda pulps reported by various mills.*³

Species of wood.	Yield per cord. ⁴
Poplar:	<i>Pounds.</i>
100 per cent domestic.....	1,000
Do.....	1,040
Do.....	1,050
Do.....	1,050
59 per cent domestic, 41 per cent imported.....	1,075
100 per cent domestic.....	1,102
Do.....	1,139
33 per cent domestic, 67 per cent imported.....	1,144
100 per cent domestic.....	1,153
59 per cent domestic, 41 per cent imported.....	1,161
100 per cent domestic.....	1,170
91 per cent domestic, 9 per cent imported.....	1,191
100 per cent domestic.....	1,200
90 per cent domestic, 10 per cent imported.....	1,209

¹ The dimensions and characteristics were determined microscopically from 52 separate fibers from the 26 different cooks made in these experiments. No effort was made to select extremely long or extremely short fibers. See also photomicrographs of pulps, Plates II to VII.

² Litchauer, Zentr. f. d. Oesterr.-ung. Papierindustrie, p. 822, vol. 23, 1905.

³ Each value is the report of 1 mill, received during the period 1907-1909.

⁴ On the percentage basis the yields of soda pulp from poplar also vary widely. Reid (Jr. Soc. Chem. Ind., pp. 273-276, vol. 5, 1886) reports a yield of 41 per cent. De Cew (Jr. Soc. Chem. Ind., pp. 561-563, vol. 26, 1907) cites a yield of 44 per cent, or 1,150 pounds per cord, from large-tooth aspen. Sindall (Paper Technology, p. 201, 2d ed. 1910) mentions a yield of 52 per cent, which is unusually high for commercial practice.

TABLE 8.—*Yields of soda pulps reported by various mills—Continued.*

Species of wood.	Yield per cord.
	<i>Pounds.</i>
Poplar 11 per cent and pine 89 per cent.....	1,000
Poplar 91 per cent and chestnut 9 per cent.....	800
Poplar 75 per cent and gum 25 per cent.....	1,000
Poplar 95 per cent and gum 5 per cent.....	1,139
Poplar 12 per cent, pine 88 per cent, and gum small amount.....	985
Poplar 3 per cent, pine 25 per cent, and maple 72 per cent.....	948
Poplar 32 per cent, pine 52 per cent, and hemlock 16 per cent.....	862
Poplar 13 per cent, pine 1 per cent, and chestnut 86 per cent.....	800
Poplar 7 per cent, pine 43 per cent, maple 45 per cent, and basswood 5 per cent.....	1,014
Poplar 9 per cent, pine 34 per cent, maple 19 per cent, beech 19 per cent, other hard woods 19 per cent.....	794
Poplar 56 per cent, maple 7 per cent, and basswood 37 per cent.....	1,043
Poplar 40 per cent; birch, maple, beech, and basswood.....	1,160
Poplar 30 per cent, cottonwood 30 per cent; maple, buckeye, willow, and lime 10 per cent each..	1,000

The several yields were all determined from the amounts of wood consumed annually by each mill and the total production of pulp in the same time. The yields represent air-dry, bleached pulp, except for a few of the mills which used coniferous woods, together with the poplars.

The experimental work of the Forest Service shows that yields of over 55 per cent (bone-dry basis) of unbleached pulp (see Table 11) can be obtained. Even the lowest yield of good unbleached pulp was not less than approximately 45 per cent. A yield of 55 per cent amounts to over 1,450 pounds of bone-dry, unbleached pulp, or over 1,600 pounds of air-dry, bleached pulp, per 100 cubic feet of solid wood. The average 128-foot cord of peeled aspen contains approximately 90 cubic feet of solid wood,¹ and on this basis would produce 1,440 pounds of air-dry, bleached pulp.

It seems evident, therefore, that considerably higher yields can be obtained from aspen than are secured in commercial practice. One of the many reasons for the lower yields of the commercial plants is probably the quality of the wood.² In the Forest Service tests the wood used was clear and sound, all defective material having been culled.

USES.

The principal use of soda poplar or aspen pulp is in the bleached form for such papers as book, magazine, antique, coated, lithograph, map, card, cover, common envelope, and writing; and wood blotting papers; also the soft, bulky papers some times required for special purposes. In making these papers longer-fibered pulps, that is, bleached rag or sulphite wood pulps, are mixed with the soda pulp in various proportions up to 80 per cent of the whole. These other fibers are added mainly for the purpose of strengthening the soda pulps, and their proportion in the mixture depends upon the desired quality of the product. The use of considerable amounts of soda poplar pulp is favored in some cases because it imparts to the sheet of paper a bulkiness and opacity not readily obtainable with ordinary sulphite or rag pulp alone. The addition of the long-fibered pulps tends to increase the cost of the products, but gives them more lasting qualities. These mixed pulps lend themselves with particular ease to the various paper-making operations, such as sizing, coloring, beating, and running on the paper machine.

The amount of various kinds of wood pulps used in the United States in 1909 and 1899 is shown in Table 9.

¹ Forest Service Bulletin 36 (rev. ed., 1910), p. 113, Woodman's Handbook, by H. S. Graves and E. A. Ziegler; also "Factors influencing the volume of solid wood in the cord," by R. Zen, Forestry Quarterly, p. 126, No. 4, vol. 1.

² In some earlier experiments by the Forest Service considerably lower yields were obtained, which were attributed to the inferior quality of the wood. See Table 15.

TABLE 9.—Amounts of mechanical, soda, and sulphite wood pulps used in the United States.

Kind of pulp.	Total pulps.				Imported pulps.	
	1909 ¹		1899 ²		1909 ¹	
	<i>Tons.</i>	<i>Per cent.</i>	<i>Tons.</i>	<i>Per cent.</i>	<i>Tons.</i>	<i>Cost.</i>
Mechanical.....	1,323,000	47	586,374	50	119,500	\$2,723,000
Soda.....	304,000	11	171,959	15	9,500	398,000
Sulphite.....	1,200,000	42	416,230	35	172,400	8,142,000
Total.....	2,827,000	100	1,174,563	100	301,400	11,263,000

¹ Bureau of the Census—Paper and Wood Pulp Statistics; preliminary report for 1909, issued Apr. 26, 1911, p. 3.

² Bureau of the Census—Bulletin 99 of the Twelfth Census, pp. 10, 12, 1901.

RECORDS OF THE SERIES TESTS.

Tables 10 to 14 give the data for the several groups of tests in which the cooking conditions were varied in series.

EXPLANATION OF DATA.

The following column headings may need explanation:

Water in chips.—The quantity of water or moisture in the chips as charged is expressed in percentage of water based on the calculated bone-dry weight of the chips.

Initial concentrations of digester liquors.—The caustic soda (NaOH) and the sodium carbonate (Na₂CO₃) concentrations are determined by analysis of the stock soda solution, and are calculated on the basis of total liquid in the charge, including moisture in the chips. The total sodium oxide (Na₂O) is calculated from the proportions of NaOH and Na₂CO₃, each reduced to the sodium-oxide basis. Grams-per-liter concentrations may be converted into the equivalent pounds per gallon by multiplying by 0.00834. What is sometimes erroneously called percentage concentrations may be obtained by dividing grams-per-liter concentrations by 10.

Causticity of liquor.—This represents the ratio of sodium oxide in the caustic soda to the total sodium oxide.

Initial volume of digester liquors.—The digester liquors consist of the stock soda solution and water charged, together with the water in the chips as charged.

Chemicals charged.—The quantities of the several chemicals charged are their dry weights based on the chemical formulæ indicated.

Duration of cooking.—Compare data with figure 3.

Apparent condensation.—This is obtained by subtracting the amount of digester liquors at the start of the cook from the amount of liquid in the digester (as read from a water gauge) just before relieving the pressure, and blowing the digester at the end of the cook. It affords a rough measure of the amount of water condensing from the steam used for cooking.

Yields.—The yields of total crude pulp, screenings, and screened pulp are calculated to a bone-dry basis, and are expressed as a percentage of the calculated bone-dry weight of the chips. The total crude pulp is the total fibrous material and uncooked chips blown from the digester.

Yields of pulp per solid cord.—In calculating yields to pounds per cord of wood a "solid cord" is considered equivalent to 100 cubic feet of solid wood, green volume, knot free. For the aspen tested, the calculated bone-dry weight per "solid cord" was 2,668 pounds. The yield of bleached pulp, which is given on the air-dry basis (10 per cent moisture), is computed by deducting the loss on bleaching and considering 90 pounds of bone-dry pulp equal to 100 pounds of air-dry pulp.

Color ratings.—These are numerical expressions of the colors of the unbleached pulps, and were determined on machine-made sheets by means of a tint photometer, according to the method described on page 54.

Average strength.—The strength tests were conducted on machine-made sheets of unbleached pulp in the air-dry condition.¹ The methods of testing are described on page 54.

Bleach required.—This represents the parts of bleaching powder (35 per cent available chlorine) required to bleach 100 parts bone-dry weight of unbleached pulp to the commercial white color.

Loss on bleaching.—This is based on the calculated bone-dry weight of unbleached pulp lost when bleaching it to the commercial white color, with the stated per cent of bleach.

Causticity of black liquor.—This was determined by analysis, and is the ratio of the sodium oxide in the caustic soda existing as such in the black liquor to the total sodium oxide in the black liquor. The latter represents the total titratable alkali in the ash resulting from calcining the black liquor.

Efficiency in the use of NaOH.—This is the ratio of the amount of caustic soda actually consumed during the cooking operations to the amount of caustic soda originally in the charge. It is calculated from the causticity of the black liquor, assuming that the soda chemicals in the black liquor are all titratable as sodium carbonate, after the liquor has been reduced to an ash.

Wood, soda ash, and bleach employed per ton of pulp.—The volume of wood is based on the average bone-dry weight of aspen used in the tests (2,668 pounds per solid cord). The soda ash represents the total soda ash of 99.1 per cent purity (58 per cent Na_2O) necessary to furnish the chemicals employed in cooking, assuming that no loss of alkali occurs in causticizing. The bleaching powder represents the dry weight of this chemical, losses in making the bleaching solutions being disregarded.

¹ The failure of the Schopper tests to show even relatively uniform variations in the strength of pulp as affected by changes in the cooking conditions can not be explained unless that the pulps were not suitable for these tests.

TABLE 10.—*Experimental cooking conditions.*¹

[Figures in italics indicate the variable cooking condition investigated in each group of tests.]

Kind of test.	Cook No.	Date of cook.	Weight of chips charged (bone-dry basis).	Water in chips.	Liquor charge.				Initial volume of digester liquors per pound of chips (bone-dry basis).	Chemicals charged per 100 pounds of chips (bone-dry basis).			Duration of cooking.			Maximum gauge pressure per square inch.	Maximum cooking temperature.	Steam pressure at digester inlet per square inch.	Apparent condensation per pound of chips (bone-dry basis).	Remarks.
					Initial concentrations.			Causticity.		NaOH.	Na ₂ CO ₃ .	Total Na ₂ O.	Total.	At zero gauge pressure.	At maximum gauge pressure.					
					NaOH.	Na ₂ CO ₃ .	Total Na ₂ O.													
Preliminary ² .	1	1910 Oct. 27	Lbs. 39.13	Per cent. 9.9	Gm. per liter. 78.0	Gm. per liter. 2.7	Gm. per liter. 63.6	Per cent. 97.5	Galts. 0.539	Lbs. 35.07	Lbs. 1.22	Lbs. 28.60	Hrs. 8.0	Hrs. 0.2	Hrs. 7.0	Lbs. 100	° F. 338	Lbs. 105	Galts. (3) 0.983	
	2	Nov. 4	39.40	9.1	80.5	2.2	63.7	97.9	.399	26.75	.75	21.18	8.0	.4	7.0	100	338	110	1.090	
	3	Nov. 11	39.09	10.0	79.7	3.8	64.6	96.6	.403	26.82	1.27	21.70	8.0	.4	7.0	100	338	170		
Group I.....	4	Dec. 9	40.33	8.2	80.2	3.1	64.0	97.1	.594	59.70	1.56	31.70	7.0	.2	6.0	98	337	169.5	3.5	970
	5	Dec. 12	39.89	9.5	80.0	3.1	63.9	97.1	.526	35.10	1.37	28.00	7.0	.2	6.0	100	338	170	1.13	1,053
	6	Dec. 16	40.00	9.2	72.1	2.5	57.4	97.4	.499	30.00	1.05	23.90	7.0	.4	6.0	100	338	170	1.14	1,075
	7	Dec. 19	39.90	9.8	71.6	2.7	57.1	97.2	.376	22.42	.86	17.90	7.0	.2	6.0	100	338	170	1.17	.953
	8	Dec. 21	40.00	9.4	80.0	4.2	64.4	96.2	.300	20.00	1.04	16.11	7.0	.2	6.0	100	338	170	1.17	.910
	9	Dec. 22	40.00	9.4	79.2	4.1	63.8	96.2	.227	15.00	.78	12.07	7.0	.2	6.0	100	338	170	1.16	.862
	10	1911 Jan. 26	40.07	8.9	80.0	5.7	65.3	94.9	.374	24.94	1.78	20.37	12.0	.6	11.0	100	338	170	1.14	31.197
	11	Feb. 13	39.98	9.1	80.0	2.4	63.4	97.8	.375	25.02	.75	19.82	6.4	.2	4.6	100	338	170	1.07	.426
Group II.....	12	Feb. 16	40.00	9.2	80.0	2.4	63.4	97.8	.375	25.00	.75	19.82	10.0	.2	9.0	100	338	170	1.15	1.125
	13	Feb. 20	40.00	9.2	80.0	2.4	63.4	97.8	.375	25.00	.75	19.82	8.0	.4	7.0	100	338	170	1.15	1.065
	14	Feb. 24	40.12	8.9	80.1	2.6	63.6	97.7	.373	24.93	.79	19.76	6.0	.2	6.0	100	338	170	1.16	.778
	15	Mar. 1	40.00	9.7	80.3	3.0	66.8	97.4	.375	25.12	.93	20.90	4.0	.4	5.0	100	338	170	1.14	.686
	16	Mar. 2	40.00	9.5	80.0	2.1	63.2	98.1	.375	25.00	.65	19.78	2.0	.4	7.0	100	338	170	1.12	.695

¹ For other conditions affecting the preparation of the pulps, see method of conducting experiments, pp. 9 to 15.² The preliminary tests were made to ascertain that the apparatus was in order and that the methods of testing were satisfactory; their results, however, are comparable with those of the other groups.³ Overflow of digester liquor through top relief valve during final stages of cooking.⁴ Part of the data for these cooks has been published previously in Forest Service Bulletin (unnumbered), Paper Pulps from Various Forest Woods, by Henry E. Surface, 1912. This bulletin also contains specimens of the bleached and unbleached pulps.⁵ Slight loss of digester liquor because of digester leakage.

TABLE 10.—*Experimental cooking conditions—Continued.*

Kind of test.	Cook No.	Date of cook.	Weight of chips charged (bone-dry basis).	Water in chips.	Liquor charge.				Initial volume of digester liquors per pound of chips (bone-dry basis).	Chemicals charged per 100 pounds of chips (bone-dry basis).			Duration of cooking.				Maximum gauge pressure per square inch.	Maximum cooking temperature.		Steam pressure at digester inlet per square inch.	Apparent condensation per pound of chips (bone-dry basis).	Remarks.
					Initial concentrations.			Causticity.		NaOH.	Na ₂ CO ₃ .	Total Na ₂ O.	Total.	At zero gauge pressure.	At maximum gauge pressure.	° F.		° C.				
					Gm. per liter.	Gm. per liter.	Gm. per liter.															
Group III.....	17	1911.	40.00	9.3	80.0	1.8	63.1	98.3	.375	25.00	.57	19.73	8.0	.4	7.0	120	350	177	.980			
	18	Apr. 11	40.00	9.0	80.0	3.0	63.8	97.3	.375	25.00	.93	19.92	7.9	.4	6.9	110	344	173	.925			
	19	Apr. 7	40.00	9.0	80.0	2.9	63.7	97.3	.375	25.00	.91	19.92	8.0	.4	7.0	100	338	170	.865			
	20	Apr. 6	40.00	8.9	80.0	2.9	63.7	97.3	.375	25.00	.91	19.92	8.0	.4	7.0	90	331	166	.865			
	21	Apr. 5	40.00	9.0	80.0	2.9	63.7	97.4	.375	25.00	.90	19.92	8.0	.4	7.0	80	324	162	.875			
	22	Apr. 4	40.00	9.5	80.0	3.0	63.7	97.3	.375	25.00	.94	19.94	8.0	.4	7.0	70	316	158	.875			
	23	Apr. 21	39.03	8.2	110.0	3.3	87.2	97.8	.273	25.02	.75	19.85	8.0	.4	7.0	100	338	170	1.243			
Group IV.....	24	Apr. 24	39.03	8.2	90.1	2.7	71.4	97.8	.333	25.00	.75	19.82	8.0	.4	7.0	100	338	170	1.240	Blown at 80 pounds pressure.		
	25	Apr. 25	39.03	8.2	70.0	2.1	55.5	97.8	.429	25.02	.75	19.85	8.0	.4	7.0	100	338	170	1.185			
	26	Apr. 28	39.03	8.2	50.1	1.5	39.7	97.8	.599	25.00	.74	19.83	8.0	.4	7.0	100	338	170	1.014			

(P. L.—127, S. L.—19.)

¹ Slight loss of digester liquor because of digester leakage.² Part of the data for this cook has been published previously in Forest Service Bulletin (unnumbered), Paper Pulps from Various Forest Woods, by Henry E. Surface, 1912. This bulletin also contains specimens of the bleached and unbleached pulps.³ Overflow of digester liquor through top relief valve during final stages of cooking.

TABLE 11.—*Yields of experimental pulps.*

Kind of test.	Cook No.	Yields (bone-dry basis).			Yields of unbleached pulp (bone-dry basis) per solid cord.	Yields of bleached pulp (air-dry basis) per solid cord.
		Total crude pulp.	Screenings.	Screened unbleached pulp.		
		<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Pounds.</i>	<i>Pounds.</i>
Preliminary.....	1	48.01	0.05	47.96	1,279	1,406
	2	50.34	.03	50.31	1,342	1,475
	3	49.31	.02	49.29	1,314	1,444
Group I.....	4	46.48	.01	46.47	1,240	1,372
	5	50.01	.01	50.00	1,334	1,467
	6	44.67	.01	44.66	1,191	1,308
	7	52.63	.03	52.60	1,402	1,533
	8	55.57	.01	55.56	1,482	1,625
	9	58.30	13.02	45.28	1,208	1,315
Group II.....	10	50.36	.08	50.28	1,341	1,487
	¹ 11					
	12	51.72	.04	51.68	1,378	1,524
	13	52.49	.05	52.44	1,400	1,524
	14	53.70	.09	53.61	1,429	1,558
	15	55.58	.44	55.14	1,471	1,586
	16	58.12	19.00	39.12	1,043	1,109
Group III.....	17	48.67	.01	48.66	1,298	1,422
	18	50.02	.02	50.00	1,335	1,461
	19	52.55	.04	52.51	1,400	1,530
	20	54.97	.02	54.95	1,465	1,612
	21	54.85	.09	54.76	1,460	1,595
	22	57.88	.13	57.75	1,541	1,666
Group IV.....	23	49.18	.02	49.16	1,311	1,432
	24	51.61	.01	51.60	1,376	1,521
	25	50.78	.01	50.77	1,354	1,483
	26	53.58	.03	53.55	1,429	1,573

¹ Cook spoiled, due to defect in apparatus.

TABLE 12.—*Properties of unbleached pulps.*¹

Kind of test.	Cook No.	Air-dry pulp sheets.			Slives per gram of bone-dry pulp.	Ash per gram of bone-dry pulp.	Average strength by Mullen tester.			Average strength by Schopper tester.		Bleach required.	Loss on bleaching.
		Natural color.	Color ratings. ²				Sheet thickness.	Total strength.	Strength per 0.001-inch thickness.	Stretch.			
			Red, green, and blue.	Parts black.									
Preliminary.....	1	Light cream brown.....	41-35-31	87	4	Per cent. 1.10	Inches. 0.0108	Lbs. per sq. in. 12.7	Lbs. per sq. in. 1.18	Meters. 1.899	Per cent. 0.80	Per cent. 8.0	1.05
	2	do.....	43-35-34	82	8	.81	.0103	16.2	1.57	2.594	1.02	8.0	1.13
	3	do.....	44-32-32	86	11	1.08	.0106	25.3	2.38	3.087	1.08	7.5	1.14
Group I.....	4	do.....	41-34-33	86	0	.95	.0104	20.1	1.93	3.898	1.40	6.0	.40
	5	do.....	45-32-32	85	0	.91	.0102	20.9	2.05	3.076	1.47	7.0	1.06
	6	do.....	41-31-30	92	0	.80	.0106	22.9	2.16	2.748	1.02	7.5	1.10
	7	do.....	41-33-31	89	15	.85	.0103	24.6	2.39	3.045	1.10	9.0	1.58
	8	Cream brown.....	38-30-27	99	508	.84	.0108	32.9	3.05	3.147	1.44	14.0	1.41
	9	Brown.....	25-19-17	133	908	1.76	.0104	33.3	3.20	3.185	1.46	29.0	1.97
	10	Light cream brown.....	43-35-33	83	15	1.75	.0102	23.9	2.34	2.695	1.26	8.0	.26
	11	Light cream brown.....	38-32-31	93	11	.80	.0104	30.9	2.97	3.169	1.24	10.0	.60
Group II.....	12	do.....	43-34-31	86	15	1.03	.0105	27.2	2.59	2.705	1.16	9.5	2.09
	13	do.....	44-35-34	81	19	.77	.0104	27.9	2.68	2.892	.90	10.5	1.88
	14	do.....	41-36-34	80	345	.71	.0105	25.6	2.44	3.432	1.16	15.0	2.94
	15	do.....	44-30-27	95	762	1.04	.0102	30.0	2.94	2.578	1.02	23.0	4.22
	16	Cream brown.....	39-32-29	94	4	.74	.0105	34.0	3.24	3.365	1.06	7.0	1.40
	17	Light cream brown.....	39-31-30	94	8	.74	.0102	32.7	3.21	3.245	1.20	8.0	1.56
	18	do.....	43-36-33	82	11	.78	.0103	27.6	2.68	3.971	1.30	9.0	1.64
	19	do.....	40-32-31	91	32	.97	.0104	24.6	2.36	3.195	1.18	10.0	1.14
Group III.....	20	Cream brown.....	42-34-32	86	154	.78	.0106	22.8	2.15	2.958	.88	11.0	1.60
	21	Light cream brown.....	41-32-31	80	127	.97	.0108	30.6	2.83	3.266	1.16	19.0	2.62
	22	Cream brown.....	44-36-33	81	0	.83	.0107	33.2	3.10	2.757	.78	8.5	1.78
	23	Light cream brown.....	43-34-32	85	0	.81	.0102	24.2	2.37	3.092	1.00	9.0	.54
Group IV.....	24	do.....	42-33-30	89	19	.79	.0108	24.8	2.30	2.668	.86	9.5	1.42
	25	do.....	42-33-30	89	182	.94	.0109	25.7	2.36	2.649	.94	11.0	.96
	26	do.....	42-33-30	89									

¹ For fiber measurements and microscopic observations of the pulps see pages 45 and 29. Photomicrographs of the fibers are shown in Plates II to VII.² The sum of the red, green, blue, and parts-black ratings in each case is 194. See footnote, page 54.³ Cook spoiled, due to defect in apparatus.

TABLE 13.—*Caustic soda consumed during cooking.*

Kind of test.	Cook No.	Causticity of black liquors.	Efficiency in the use of NaOH.	NaOH consumed per 100 pounds of wood (bone-dry basis).	NaOH consumed per 100 pounds of unbleached pulp (bone-dry basis).
		Per cent.	Per cent.	Pounds.	Pounds.
Preliminary.....	1				
	2	13.4	86.2	23.1	45.9
	3	2.2	97.8	26.2	53.2
Group I.....	4	22.3	77.0	30.6	65.9
	5	21.4	77.9	27.3	54.6
	6	14.3	85.3	25.6	57.4
	7	15.3	84.2	18.9	36.0
	8	17.2	82.1	16.4	29.5
	9	2.8	97.1	14.6	32.3
Group II.....	10				
	11	4.7	95.0	23.7	47.1
	12	4.6	95.4	23.9	46.2
	13	3.4	96.5	24.1	46.0
	14	10.2	89.6	22.3	41.6
	15	18.0	80.7	20.3	36.8
	16	25.5	74.0	18.5	47.3
Group III.....	17	5.7	94.2	23.6	48.4
	18	4.7	95.2	23.8	47.6
	19	14.4	85.2	21.3	40.6
	20	20.1	79.3	19.8	36.1
	21	27.1	72.1	18.0	32.9
	22	26.0	73.2	18.3	31.7
Group IV.....	23	19.4	80.2	20.1	40.9
	24	18.1	81.5	20.4	39.5
	25	17.8	81.8	20.5	40.4
	26	10.3	89.5	22.4	41.9

¹ Cook spoiled, due to defect in apparatus.TABLE 14.—*Wood, soda ash, and bleach employed per 2,000-pound ton of air-dry pulp (10 per cent moisture) based on experimental results.*

Kind of test.	Cook No.	Unbleached pulp.		Bleached pulp.		
		Wood.	Soda ash (58 per cent Na ₂ O).	Wood.	Soda ash (58 per cent Na ₂ O).	Bleaching powder (35 per cent available chlorine).
		<i>Solid cords.</i>	<i>Pounds.</i>	<i>Solid cords.</i>	<i>Pounds.</i>	<i>Pounds.</i>
Preliminary.....	1	1.41	1,853	1.42	1,872	145.5
	2	1.34	1,308	1.36	1,322	145.6
	3	1.37	1,367	1.38	1,384	136.5
Group I.....	4	1.45	2,117	1.46	2,126	108.4
	5	1.35	1,738	1.36	1,757	127.4
	6	1.51	1,661	1.52	1,681	136.5
	7	1.28	1,057	1.30	1,074	164.6
	8	1.22	901	1.23	912	255.6
	9	1.49	828	1.52	844	532.5
Group II.....	10					
	11	1.34	1,259	1.34	1,259	144.3
	12	1.31	1,191	1.31	1,196	181.2
	13	1.28	1,172	1.31	1,196	174.7
	14	1.26	1,145	1.28	1,167	192.7
	15	1.22	1,177	1.26	1,211	278.1
	16	1.72	1,571	1.80	1,642	432.3
Group III.....	17	1.33	1,258	1.41	1,276	127.8
	18	1.35	1,235	1.37	1,254	146.2
	19	1.28	1,178	1.31	1,196	164.7
	20	1.22	1,126	1.24	1,137	182.1
	21	1.23	1,128	1.25	1,148	201.2
	22	1.17	1,071	1.20	1,101	351.2
Group IV.....	23	1.38	1,254	1.39	1,276	155.7
	24	1.31	1,191	1.32	1,199	162.9
	25	1.33	1,214	1.35	1,232	173.5
	26	1.26	1,149	1.28	1,160	200.0

¹ Cook spoiled, due to defect in apparatus.

METHODS FOR AUXILIARY TESTS.

In determining bone-dry weights, properties of pulps, and concentrations of soda liquors, the following methods were employed:

BONE-DRY WEIGHTS.

In practically all determinations involving exact quantities of wood, pulp, or screenings, either actual or calculated bone-dry weights were used. The actual bone-dry weight is the weight of the material after having been dried to constant weight in an oven with good circulation of pure air at a temperature of 104-106° C.¹ Usually instead of drying the entire quantity of material, its "bone-dry factor," or the ratio of the bone-dry weight to the weight before drying, was determined by means of a small sample. The calculated bone-dry weight is the weight obtained by use of this factor. The errors in calculated bone-dry weights were found by actual test to be less than 0.3 per cent.

PROPERTIES OF UNBLEACHED PULP.

Color.—The color of a pulp was determined by visual observation and also by means of an Ives new construction tint photometer. The standard for comparison was a block of magnesium carbonate, which affords photometer readings of 100 each for the red, green, and blue color screens used. The sum of the three readings for a pulp measures its "whiteness," and this sum subtracted from 300² (the sum of the three readings for a surface as white as the standard) measures the "parts black" rating of the pulp. The higher the "parts black" value the darker is the pulp. This method of expressing relative "darkness" of different pulps is reliable only when the pulps are of approximately the same hue, as in the case of these experiments.

Shives.—Shives in pulp are the small bundles of wood fibers which were not reduced by the cooking and subsequent operations, and which were not removed by the pulp screens. For the determination, a three-tenths-gram portion of pulp, the bone-dry factor of which was known, was thoroughly broken up in a small Erlenmeyer flask and deposited on a 70-mesh sieve in an even deposit or sheet covering 9.66 square inches. This sheet was "couched" on a silk cloth and then transferred to a glass plate and dried in an oven. When the plate with the deposit was placed in front of an incandescent lamp the shives could easily be counted with the eye. In cases where the number was large, a glass plate divided into quarter-inch squares was placed on top of the pulp and a small area was examined instead of the whole. Knowing the area examined and the bone-dry weight of the pulp sheet, the number of shives per gram of bone-dry pulp could be calculated.

Ash.—The ash was determined by burning a bone-dry sample of unbleached pulp of known weight in a platinum or porcelain dish over a Bunsen flame until the ash produced was free from carbon and of a white or grayish-white color. The percentage of ash is based on the bone-dry weight of the pulp.

Strength.—The strength of the pulp sheets made on the paper machine was determined by a Mullen paper tester and by a Schopper breaking-length testing instrument. The pulp was tested in the ordinary air-dry state for the conditions that prevailed in the laboratory. The Mullen test, or "pop test" as it is sometimes called, was made by clamping a single sheet, accurately measured for thickness, between a rubber diaphragm and a polished metal ring, and then, by means of liquid under pressure, forcing the diaphragm against the pulp sheet until it burst through the aperture. The pressure on the liquid in pounds per square inch, or "points," is read from a

¹ The weight was considered constant when the decrease was not more than 0.1 per cent during an additional hour's drying at this temperature.

² At the time of these experiments the shutter of the instrument used had been injured and could not be opened more than 64.7 points. The other aperture was then reduced to this size and the value 64.7 was used in place of 100 for a wide-open aperture, and 194 (3 times 64.7) was used in place of 300. The results obtained for the various pulps were sufficiently accurate for comparison with each other.

gauge. For each pulp 20 sheets whose thickness varied between 0.010 and 0.011 inch were tested. The average strength in pounds per square inch per 0.001 inch thickness is the quotient of the average test value divided by the average thickness in thousandths of an inch. A quantity one-tenth of this value is sometimes used in expressing results, and is called the "strength ratio."¹ The Schopper tester measures in kilograms weight the tensile stress required to break a strip of pulp 15 mm. wide. At the same time the instrument registers the "per cent stretch," which is the strain or elongation of the strip just before breaking, and is expressed as a percentage of the original length. The "breaking length" is the length of sheet which, if suspended, would break of its own weight, and when expressed in meters is determined by multiplying the weight in kilograms required to break the strip by its testing length in millimeters (180 mm.), and dividing the product by the weight in grams of the portion of the strip subjected to test. Five strips of pulp were tested in the "machine direction" of the sheet and five across the machine direction, and the average values for the two directions determined.

Bleach required.—The bleaching solution was made by mixing bleaching powder (calcium oxy-chloride or chloride of lime) with water and allowing the mixture to settle so that a clear solution was obtained. The strength of this solution was determined by titrating 5.00 cc. against fifth normal arsenious acid solution, using a solution of starch paste and potassium iodide as indicator. The number of cubic centimeters of arsenious acid used, multiplied by 4.0514, gave the strength of the bleaching solution in grams per liter of "35 per cent bleach," or bleaching powder, in which 35 per cent of its weight is chlorine available for bleaching purposes. The bone-dry weight (about 50 grams) of the pulp sample used for the bleaching determination was first calculated by means of its bone-dry factor. The sample was then thoroughly broken up in water² to form a uniform pulp mixture. A quantity of the bleaching solution containing a known weight of "35 per cent bleach" was added and the mixture diluted with water² to approximately 2,500 cc. This mixture was kept at a temperature of 40° C. until the bleach was exhausted, as determined by starch-iodide indicator. The bleached fiber was then thoroughly washed free from bleach residues and made up into sheets on a small hand mold. These sheets, when air-dry, were compared with air-dry standard color sheets made in a similar manner from five or six commercially bleached soda pulps mixed in equal proportions. If the first determination on the experimental pulp did not give as white a color as the standard, the process was repeated on other samples until the standard color was attained as nearly as possible.³ The weight of 35 per cent bleach required to produce the standard color is expressed as a percentage of the bone-dry weight of the pulp. The bleaching operations were performed in enameled jars provided with agitators and placed in a tank of water whose temperature could be regulated by an electric heater. It was found best to start the bleaching in the late afternoon or evening, so that the bleach was exhausted sometime the next morning. The comparisons with the standard color sheets should be made at about the same time each day, using light from a north window.

Loss on bleaching.—For determining the loss on bleaching, a sample of about 2 grams of pulp was thoroughly broken up in water and bleached in a 250 cc. Erlenmeyer flask, using as near as possible the conditions which produced the standard

¹ "Strength factor" or "points per pound" is distinguished from "strength ratio" by the former being obtained by dividing the "pop test" by the weight in pounds of a ream of paper. The size of a ream varies, but for a standard of comparison a ream of 500 sheets, 24 by 36 inches, is usually preferred for determining the strength factor.

² The water should be neutral so far as its action on pulp and on bleaching powder solution is concerned. The use of distilled water is preferable.

³ Actual tests have shown that this method gives results almost identical to those secured in pulp-mill operations. The method of determining the amount of bleach required by adding an excess of bleaching powder and titrating the unconsumed excess after the pulp is bleached sufficiently white, gives much lower results.

color in the samples tested for the determination of the amount of bleach required. The bleached sample was thoroughly washed, first with hot distilled water and afterwards with ethyl alcohol. Its bone-dry weight was then determined. The percentage loss on bleaching is based on the bone-dry weight of the unbleached pulp, which had been calculated from its bone-dry factor.

Microscopic examinations.—Representative portions from the pulp sheets were soaked in water, teased apart with a needle, stained with Bismarck brown, dehydrated with absolute ethyl alcohol, cleared in xylol, and made into permanent mounts with Canada balsam. Photomicrographs of these mounts magnified 65 diameters were used in studying the individual fiber characteristics. Further microscopic study of each of the individual mounts was also made, using different magnifications, and such features were observed as the apparent strength of cell walls, the prominence of cell markings and the presence of vessels, fiber bundles (shives), and ray cells. The general shape and condition of the fibers and the distinguishing characteristics for the species were noted. By means of a micrometer eyepiece about 50 unbroken fibers from the various mounts were measured for length and breadth at the middle of the fibers, and the average thickness of the cell walls was roughly estimated. The fibers were selected at random, no effort being made to select extremely long or short ones.

ANALYSES OF SODA LIQUORS.

The caustic-soda solutions charged and the black liquors from the leached pulps were examined for their contents of cooking chemicals, in the first case to calculate sizes of charges, and in the second to determine the consumption of caustic soda during cooking.

Caustic soda liquor.—The examination of the caustic soda liquor was conducted as follows: A 10 cc. portion was titrated against normal sulphuric acid, using phenolphthalein as first indicator and methyl orange indicator to finish the titration. Letting Y =the number of cubic centimeters of normal acid solution required for the first end point and X =the number of cubic centimeters required for the final end point, the following equations were used for calculating the concentration of caustic soda (NaOH) and the causticity:

$$4(Y - (X - Y)) = \text{grams per liter of NaOH.}$$

$$\frac{100(Y - (X - Y))}{X} = \text{per cent causticity.}$$

Black liquor.—The examination of black liquor was conducted as follows:

(1) A 50 cc. portion of black liquor was evaporated to dryness in a platinum dish. The residue was ashed over a Bunsen burner and the soluble salts were leached out with hot distilled water. The entire solution obtained was titrated with normal sulphuric acid, using methyl orange as indicator. The number of cubic centimeters of acid required to produce the end point multiplied by 0.62 gives the grams per liter of total sodium oxide (Na_2O) in the black liquor.

(2) A 100 cc. portion of the same black liquor was mixed with 50 cc. of 10 per cent barium chloride solution in a 500 cc. calibrated flask. The mixture was then diluted to 500 cc. with neutralized or freshly distilled water free from carbon dioxide and thoroughly agitated. After settling, 50 cc. of the clear supernatant liquor were titrated with tenth normal hydrochloric acid, using phenolphthalein as indicator. The number of cubic centimeters of acid required for the end point multiplied by 0.401 gives the number of grams per liter of free caustic soda (NaOH) in the black liquor.

(3) The causticity of the black liquor was calculated from the following equation:

$$\frac{A(0.775)100}{B} = \text{per cent causticity.}$$

In which:

A =the number of grams per liter concentration of caustic soda (NaOH).

B =the number of grams per liter concentration of total sodium oxide (Na_2O).

AUTOCLAVE TESTS ON ASPEN.

A few autoclave tests on aspen (*Populus tremuloides* Michx.) were made in 1909.¹ The ordinary soda process was employed, but the digester used was a horizontal, rotary autoclave, made of 6-inch steel pipe, with a capacity of about 2 gallons. As the heat was furnished by Bunsen burners, there was no condensation or loss of liquid through overflow to modify the cooking conditions. Cooks were not blown, but the digester was quickly cooled to room temperature and then dumped. The pulps were thoroughly washed with cold water and screened on a small diaphragm screen through slots of 0.006 inch width. The test material was cut from fairly young growth near Ridgeway, Colo. Portions of the logs tested, especially the centers and around knots, were discolored a dull reddish-brown, probably due to incipient fungous attack; otherwise the wood seemed to be sound. Chips were prepared in the manner described on page 15. Their sizes were five-eighths inch (with the grain) by three-sixteenths to one-fourth inch by one-half inch to 6 inches (both across the grain).

The data resulting from the tests are shown in Table 15. The column headings have the same significance as those in Tables 10 to 14, except as otherwise indicated. However, in the bleaching tests the standard color matched was that of bleached sulphite pulp, and, as soda poplar pulp in commercial operations is never bleached to so white a color, the test data should be reduced somewhat in estimating the commercial value for bleach required. The values for loss on bleaching also are probably a little greater on this account.

The tests fall naturally into two groups. One of these consists of cooks 1, 2, and 4, in which the concentration of caustic soda in the cooking liquors was varied. The other consists of cooks 3 and 5, in which the duration at maximum pressure was the chief variable. Increases either of concentration or of duration resulted in decreases in the yield of pulp, loss on bleaching, and bleach required, except possibly in the case of one cook. All of the pulps produced were thoroughly cooked. The yields, as compared with those secured in the more recent tests (see Table 11), were uniformly very low and the losses on bleaching very high. The difference may be due to the methods and apparatus used or to deterioration of the wood from fungous attack, or to both. If the wood had been perfectly sound, it does not seem probable that the lower yields would have been accompanied by the higher amounts of bleach required and the larger losses on bleaching, even though these effects were slightly augmented by the higher standard of bleaching.

TABLE 15.—Cooking conditions and results of autoclave tests on aspen.

Cook No.	Date of cook.	Weight of chips charged (bone-dry basis).	Water in chips.	Liquor charge.				Initial volume of digester liquors ² per pound of chips (bone-dry basis).	Chemicals charged per 100 pounds of chips (bone-dry basis).		
				Initial concentrations. ²			Causticity.		NaOH.	Na ₂ CO ₃ .	Total Na ₂ O.
				NaOH.	Na ₂ CO ₃ .	Total Na ₂ O.					
		Lbs.	P. ct.	Grams per liter.	Grams per liter.	Grams per liter.	P. ct.	Galls.	Lbs.	Lbs.	Lbs.
1	1909.										
2	May 25	1.652	33.5	80	7.4	66.3	93.5	0.375	25.0	2.3	20.7
3	May 27	1.652	33.5	50	1.8	39.8	97.5	.599	25.0	.9	19.9
4	June 2	1.652	33.5	90	4.3	72.3	96.5	.386	29.0	1.4	23.3
5	June 8	1.304	18.3	30	1.4	24.1	96.5	1.000	25.0	1.2	20.1
6	July 3	1.920	15.0	90	4.3	72.3	96.5	.390	29.3	1.4	23.5

¹ These tests were made by Mr. Edwin Sutermeister, formerly in charge of the pulp-testing laboratory of the Forest Service at Washington, D. C.

² The water in the chips when charged is not taken into consideration.

TABLE 15.—Cooking conditions and results of autoclave tests on aspen—Continued.

Cook No.	Duration of cooking.			Maximum gauge pressure per square inch.	Yields (bone-dry basis).			Properties of unbleached pulps. ¹		
	Total.	At zero gauge pressure.	At maximum gauge pressure.		Total crude pulp.	Screenings.	Screened pulp.	Ash.	Bleach required.	Loss on bleaching.
	<i>Hrs.</i>	<i>Hrs.</i>	<i>Hrs.</i>	<i>Lbs.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>	<i>P. ct.</i>
1	8.2	0.3	7.0	110	41.10	0.10	41.00	1.40	15.4	3.92
2	8.5	.3	7.0	110	44.23	.03	44.20	1.27	14.7	4.08
3	4.6	.3	3.0	110	40.50	.10	40.40	1.35	14.3	4.39
4	8.0	.2	7.0	110	46.97	.07	46.90	1.25	15.8	4.68
5	8.0	.3	7.0	110	36.00	.00	36.00	1.42	10.0	2.56

(P. L.—66—1, S. 683.)

¹ The pulps produced were of good strength and of a fair degree of hardness; the color was very light reddish-brown. Shives were very few in number or almost absent.

p manufacture.

liquors at start of cook.

Specific gravity.	Concentration of NaOH.	
¹ 1.09 (²)	6 per cent ¹	F
¹ 1.03	2 per cent ¹ (?).....	
¹ 1.09	7 per cent ¹	
¹ 1.08	7 per cent ¹	
³ 1.06-1.12		
¹ 1.08		
¹ 1.09-1.11	6-9 per cent.....	
(²)	6-8 per cent.....	
¹ 1.07-1.12	5-10 per cent ¹	
(²)		
¹ 1.07-1.11	5-7 per cent Na ₂ O.....	
¹ 1.07		
¹ 1.09		
¹ 1.09-1.11	7-9 per cent ¹	
¹ 1.07-1.11	5-7 per cent ¹	
¹ 1.10		

sure and blowing, 45-60 minutes; total

TABLE 16.—Cooking conditions employed in the soda process of wood-pulp manufacture.

Reference No.	Practice followed.	Digester.				Quantity of chemicals charged.		Quantity of cooking liquor charged.		Cooking liquors at start of cook.					Cooking pressure per square inch.	Cooking temperature.	Durations of cooking.			Blowing pressure per square inch.	Authority. ⁷
		Kind.	Size.	Wood capacity.	Manner of heating.	Actual caustic soda (NaOH).	Total soda expressed as carbonate.	Per cook.	Per cord.	Density.			Concentration of NaOH.	Causticity.			Total.	From start till cooking pressure is reached.	At cooking pressure.		
										Baumé.	Twaddle.	Specific gravity.									
1	Watt and Burgess process.....		Feet.					Gallons.	Gallons.	12°	18°	1 1.09	6 per cent ¹	Per cent.	Pounds.	° F.	Hours.	Hours.	Hours.	Pounds.	Griffin and Little, 1894.
2	do.									(?)	(?)	(?)			60					Clapperton, 1907.	
3	Sinclair's process.....	Cylindrical, stationary, vertical.			Direct fire.			60 per cwt. dry wood.							180-200			0.5 or less.	Not blown.	Wait, 1907.	
4	Loughton's process.....									4°	16°	1 1.03	2 per cent ¹ (?).....		180					Loughton; Griffin and Little, 1894.	
5	European practice (1870).....					336 lbs. per ton green wood.									150-180	360-375				Silcox, 1875.	
6	American practice (1870).....	Cylindrical, stationary.	16 by 5	1 cord.	Direct fire or steam jacket.					12°	18°	1 1.09	7 per cent ¹		65 or more.	6			65 or more.	Hofmann, 1873; Watt, 1907.	
7	American practice (1880-1890).....	do.	27 by 7	4.3 cords.	Live steam.....	441 lbs. per cord ¹		3,400	1 765	11°	16°	1 1.08	7 per cent ¹		110	3-9-10	2-3	7	45	Congdon, 1889; Watt, 1907.	
8	do.									8-15° at 60° F.	12-21°	1 1.06-1.12									
9	do.	Cylindrical, stationary, vertical.			Jacket, coils, or direct fire.			More than 700.		11° for poplar.	16°	1 1.08			90-110	8-10				Griffin and Little, 1894.	
10	do.	Rotaries.			Live steam.....			700		12-14° at 60° F.	18-22°	1 1.09-1.11	6-9 per cent.....								
11	Modern practice.....									(°)	(°)	(°)	6-8 per cent.....		90-110			8-10		Cross and Bevan, 1900.	
12	Modern practice (American).....	Cylindrical, stationary.	27 by 7	4.5 cords.	Live steam.....	450(?)—520 lbs. per cord. ¹	635(?) to 1,320 lbs. per cord. ¹	4,000	1 800	10-15° at 60° F.	14-24°	1 1.07-1.12	5-10 per cent ¹	92-94	100-120	8-13	2-3	6-10	75	International Library of Technology, 1902.	
13	do.	vertical.						5,000	1,100	(°)	(°)	(°)			100-110		(°)	(°)		Clapperton, 1907.	
14	Modern practice (Canadian).....	do.					800-950 lbs. per cord.													De Cew, 1907.	
15	Modern practice.....					12-20 per cent of weight of wood.				10-14°	15-22°	1 1.07-1.11	5-7 per cent Na ₂ O.....		130-160	360	4-6			Stevens, 1908.	
16										10°	11°	1 1.07			132-147		4-6			Schubert; Stevens, 1908.	
17										12°	18°	1 1.09			88-118					Ernst Müller; Stevens, 1908.	
18										12-14°	18-22°	1 1.09-1.11	7-9 per cent ¹		73-147		4-6			Klemm; Stevens, 1908.	
19	Modern practice.....	Stationary or revolving.			Live steam.....	16-20 per cent				10-14°	15-22°	1 1.07-1.11	5-7 per cent ¹		70-80		4-6			Sindall, 1908.	
20	Modern practice (American).....				do.										100-130	338-355				Beveridge, 1911.	
21	Modern practice.....	Stationary.			do.					13°	20°	1 1.10			100-150			6-8		Cross, Bevan, and Sindall, 1911.	
22	Modern practice (Swedish).....			8.5 cu. meters (=300 cu. ft.) of chips.		637 kilos (=1,400 lbs.) ¹ Na ₂ O for charge.		6,000 liters (=1,321 galls.) ¹							125	353		1-2		Tienefeld; Beveridge, 1911.	

¹ Calculated from other data given.² Strong solution of caustic soda.³ In addition to the total time of cooking Congdon reports: Time required for charging digester, 30-45 minutes; for relieving pressure and blowing, 45-60 minutes; total period for a cook, 11-11½ hours.⁴ Not specifically known whether time is total duration or duration at maximum pressure.⁵ Stronger liquors than Ref. No. 9.⁶ Less than 10-12 hours.⁷ See Bibliography at end of appendix, for more detailed references.

TABLE 17.—Cooking conditions employed at specific American soda-pulp mills.¹

Reference No.	Date of report.	Digester.				Quantity of chemicals charged.		Quantity of cooking liquor charged.	
		Kind.	Size.	Wood capacity.	Manner of heating.	Actual caustic soda (NaOH).	Total soda expressed as carbonate.	Per cook.	Per cord.
1	1909	Cylindrical, stationary, vertical.	<i>Fwd.</i>	<i>Cords.</i> 3	Live steam or steam jacket.	.....	<i>Pounds per cord.</i> 1,000.	<i>Gallons.</i> 2,800.	<i>Gallons.</i> 330-1,000
2	1909	do.....	28 by 7	3-3.5	Live steam.	720-860 pounds per cord. ²	1,030-1,300 ²	3,000	2975-1,150
3	1909	do.....	.....	3	(Steam jacket.	.....	1,000.	3,500	2 830
4	1907	do.....	49 by 10	15	Live steam.	625 pounds per cord.	.....	2,500	2 870
5	1907	Cylindrical, rotary, horizontal.	20 by 7	3.5	do.	25 per cent.	.....	13,000	2 750-2 780-900
6	1907	Cylindrical, stationary, vertical.	30 by 8	5.5	Live steam.	=630 pounds per cord.	.....	3,100	.....
7	1907	do.....	40 by 9	.....	do.	.....	.....	.....	.....
8	1907	do.....	30 by 8	5.5	do.	.....	.....	9,300	2 775
9	1907	do.....	42 by 6	12	do.	.....	885.	3,900	900
10	1904	do.....	27 by 7	4	do.	2,792 pounds per charge. ²	.....	4,200	.....
11	1903	Cylindrical, stationary, vertical (welded).	29 by 7	.....	do.	610 pounds per cord.	.....	2,930	840
12	1910	do.....	29 by 7	3.5	do.	656 pounds per cord.	.....	3,200	800
13	1910	do.....	30 by 7	4.0	do.	.....	.....	.....	.....

¹ Each report represents a single mill except as specified for reference No. 11.² Calculated from other data given.³ Statement by A. G. Fañe, Jr., in United States House of Representatives Doc. 1502, 60th Cong., 2d sess., 1909. Conditions employed by mills of the New York and Pennsylvania Co.

TABLE 17.—Cooking conditions employed at specific American soda-pulp mills—Continued.

Reference No.	Cooking liquors at start of cook.				Cooking pressure per square inch.	Durations of cooking.			Blowing pressure per square inch.
	Density.		Concentration of NaOH.	Causticity.		Total.	From start till cooking pressure is reached.	At cooking pressure.	
	Baumé.	Twaddell.							
1	7-12°	111-118°	1.05-1.09	Equivalent of 1 pound soda ash per gallon . .	Pounds. 110-120	Hours. 8-12 (3 for poplar).	Hours. 2-3	Hours. 5-10	Pounds.
2	14°	122°	1.11	9 per cent ² .	110	10-12	1.5-1.8	8.2-10.5	
3	10-15°	14-24°	1.07-1.12	5-10 per cent ¹ .	110-120	9.5-10	1-2	7.5-9	
4	7.5°	110°	1.05	Equivalent of 0.95 pound total alkali per gallon.	75	5.8	1	4.8	75.
5	13-14°	120-22°	1.10-1.11	8.5-10 per cent.	110	7.5			Not blown.
6	14-16°	122-26°	1.11-1.13		100	6-8			
7	14-16°	122-26°	1.11-1.13		100	6-8			
8	11-12°	17-18°	1.08-1.09		110	5.5-6			
9	10.5°	116°	1.08		105	10			
10	11°	16.4°	1.081	6 per cent Na ₂ O.	110			8	
11	11.5-12°	118°	1.09	8 per cent ¹ .	125-130	3-6-8			
12	12°	18°	1.091	8 per cent.	110	8	2.5	5.5	110.
13	12°	18°	1.091	9 per cent.	110-120	4.5-6	1.5-2	3-4	75.

¹ Calculated from other data given.² Statement by A. G. Paine, jr., in United States House of Representatives Doc. 1502, 60th Cong., 2d sess., 1909. Conditions employed by mills of the New York and Pennsylvania Co.³ Not specifically known whether time is total duration or duration at maximum pressure.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE



No. 81

Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief, and
the Federal Horticultural Board, C. L. Marlatt, Chairman.

March 31, 1914. .

THE POTATO QUARANTINE AND THE AMERICAN POTATO INDUSTRY.

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INTRODUCTION.

In September, 1912, a quarantine order was issued by the Secretary of Agriculture prohibiting the importation of potatoes into the United States from the British Isles, Germany, Austria-Hungary, and from Newfoundland, St. Pierre, and Miquelon, on account of the potato wart. In December, 1913, an additional temporary quarantine was laid against Canada and all the countries of Europe, pending further investigations of the occurrence of powdery scab and the establishment of a system of inspection on the part of foreign governments that will provide for the certification of potatoes offered for export to the United States, to the effect that they are free from disease, that they were grown in a disease-free locality from which the American quarantine has been lifted, and that in other respects they conform to the regulations established by this Government.

The discussion of these quarantines has focused public attention on the potato question to an unusual degree and has emphasized the need for available information concerning the reasons for the quarantines, the nature of the new regulations, and the general status of the potato industry. This bulletin is intended as a contribution to this end. It is sought also to outline a constructive policy for future development that will lessen losses from disease and other wastes and place potato culture on a basis more profitable to the producer, while at the same time permanently reducing the cost to the consumer of this staple food.

NOTE.—This bulletin tells of the necessity for establishing a quarantine against potatoes from certain countries, gives brief descriptions of the potato diseases that have been imported, indicates some of the agencies by which these diseases have been spread over this country, and gives information that potato growers should have in advance of the planting season. It is intended for general distribution.

REVIEW OF THE POTATO-DISEASE SITUATION.

When seeking protection from new plant diseases we must be guided by past experience and by our knowledge of the general principles controlling the occurrence and spread of plant parasites. It is evident that agriculture in general bears a burden that increases from year to year as new diseases or insect enemies appear. In colonial times and up to 1840 the potato seems to have been free from many serious pests that have come in since. We now list 18 or 20 diseases, not including insects, that attack potatoes in some part of the United States. The yearly loss from them is difficult to estimate, but the injury from tuber rots and related troubles was recently placed by the Department of Agriculture at over \$30,000,000 annually, and diseases which attack the crop in the field probably reduce the value of the harvest by another \$30,000,000 per annum.

Not only do new parasites appear at frequent intervals, but they can rarely, if ever, be exterminated. A plant disease, once established here, is likely to be with us forever. Under these circumstances it is to the credit of American farmers that they have, during the last generation, by the adoption of scientific methods of fertilization and culture and by spraying and seed treatment for diseases, maintained the average yield per acre of the country and in the more progressive sections considerably increased it. On the other hand, the average yield is still only about half what it might be, as judged by European standards, and the cost of spraying, increased fertilizers, etc., constitutes a heavy annual tax on the grower.

INTRODUCED PARASITES THE MORE DANGEROUS.

Plant parasites may be divided into two classes, those endemic or native to the country and those introduced from other countries. It is a general principle, fully established by experience, that parasites introduced from other continents or distant parts of the same continent are more injurious than the native parasites of the same crop and more virulent and destructive in their new habitat than they had been at home.

The United States has had many costly examples of this fact, among which may be cited the gipsy moth, the brown-tail moth, the codling moth, the asparagus rust, the hollyhock rust, and that recent immigrant from the Orient, the chestnut bark disease, which is threatening to destroy our chestnut forests.

Several potato diseases are of foreign origin. The examples mentioned below are of special interest.

LATE-BLIGHT.

In the period from 1830 to 1842 there was introduced into both Europe and America a new potato disease which causes a blighting of the foliage, followed by decay of the tubers. This disease, called

late-blight, is worst in moist, not too hot, weather, when it may spread with incredible rapidity, ruining the most vigorous field in three or four days. The same fungus spreads to the tubers, producing a typical dry rot in dry storage, which may become a wet rot in damp soil through bacterial action. The cause of this disease is the late-blight fungus (*Phytophthora infestans*), and its original habitat is believed to be South America. It gained headway soon after its introduction, and in 1845 nearly destroyed the potato crop of Europe, especially in Ireland, and did much injury in America. It has been present every year since to a greater or less extent, and serious outbreaks have recurred periodically when weather conditions favored its development. In North America it is most serious in the northeastern part of the United States and the adjacent provinces of Canada. Thorough spraying with Bordeaux mixture will control it, but the losses are nevertheless still large. There is no hope of the extermination of this disease. Potato growers will always have it to reckon with.¹

BLACK-LEG.

A disease marked by the blackening and shriveling or softening of the base of the stalk, a typical curling and yellowing of the foliage, and in late cases by an infection and partial decay of the tuber has been introduced from Europe comparatively recently, probably having come first to Canada and thence to Maine. It is a bacterial trouble,² transmitted in the seed potatoes. Two points are of special interest: (1) The widespread distribution it has secured within a few years, because seed potatoes are shipped from the district which was the original center of infection to nearly every State in the Union; (2) black-leg takes on a more virulent form under southern conditions and may destroy 10 to 75 per cent of a crop in Virginia when the seed farm in the North had much less of it.

Rigid methods of seed selection and seed treatment will control the disease, and these must be insisted upon.³

SILVER SCURF.

An example of the rapid spread of an imported fungus is afforded by the silver scurf (*Spondylocladium atrovirens*). This is a superficial parasite of the potato tuber, beginning as a brown mold on the surface. Later the infected areas take on a glistening silvery gray color, and finally the tubers shrivel more or less, due to loss of

¹ A complete description of the late-blight has been given by Jones, Giddings, and Lutman, in "Investigations of the potato fungus *Phytophthora infestans*," U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 245, 1912. Obtainable from the Superintendent of Documents, Government Printing Office, for 30 cents.

² *Bacillus phytophthorus* Appel and related forms.

³ The reader desiring more information on black-leg is advised to procure Bulletin 174 of the Maine Agricultural Experiment Station, Orono, Me.

moisture. Silver scurf has been known in Europe for many years, but it was not noticed in America, except in one instance (by Dr. Clinton in Connecticut in 1907), until 1912, when it appeared on potatoes from nearly every State from Maine to Florida and westward to Wisconsin. It is now thoroughly established here and, though a minor trouble, adds another to the agencies which disfigure potatoes. There is evidence to justify the fear that silver scurf may become more injurious in the United States than it has been in Europe.¹

Other potato parasites have come from the far West or from the South. The migration of the Colorado potato beetle from the Rocky Mountain region is well known. Two diseases, the southern bacterial brown-rot and the *Fusarium* wilt, appear to be of southern, possibly tropical, origin, though this is not fully established.

THE WART DISEASE.

Potato wart, black scab, or canker is a disease which transforms the tubers into irregular, warty excrescences, at first greenish or white, then black and decaying. It is a fungous disease (*Synchytrium endobioticum*) of comparatively recent discovery, first described from Hungary in 1896 and found in England about 1902 and in Westphalia in Germany in 1908. It has spread considerably during the past decade until it seems firmly established in England and Scotland, has gained a foothold on the coast of Ireland, and has crossed the Atlantic to Newfoundland, where Dr. H. T. Güssow, Dominion botanist, discovered it in 1909. Fortunately, it has not yet been found on potatoes grown in the United States.

Most authorities consider it one of the very serious diseases of the potato, as it converts the tuber into an ugly, irregular, and utterly worthless article, and when established in the soil will attack the succeeding crops and prevent the growing of potatoes in such infected soil for many years.

The countries where the wart occurs have for the most part taken vigorous measures to suppress it, and other nations have endeavored to prevent its introduction. It was primarily on account of this trouble that the Secretary of Agriculture issued Quarantine Order No. 3, September 20, 1912, prohibiting the entry of potatoes into the United States from Newfoundland, the islands of St. Pierre and Miquelon, the United Kingdom (including England, Scotland, Wales, and Ireland), Germany, and Austria-Hungary, although powdery scab was also taken into consideration at that time.²

¹ For further details, see the paper in Circular 127, Bureau of Plant Industry, U. S. Department of Agriculture, by I. E. Melhus, entitled "Silver scurf, a disease of the potato." Obtainable from the Superintendent of Documents, Government Printing Office, for 5 cents.

² For further information on the wart disease, see Farmers' Bulletin 489.

POWDERY SCAB.

Powdery scab is a tuber trouble, differing from the common scab mainly in the following particulars:¹ The scab spots, or sori, are more often circular and not usually as great in diameter as those of the common (*Oospora*) scab. They first appear as discolored, slightly raised spots covered by the epidermis, which later breaks away, leaving a pit, filled at maturity with a brownish dust, the spore balls of the parasite. With powdery scab there is less of a corky layer formed under the spot than is the case with common scab. For this reason there is a loss of moisture in storage and the eventual formation of a depressed spot. In severe attacks of powdery scab there is a cankerous stage or eating away of the tuber, which nearly or quite destroys its value. Finally, there is a great difference between the organisms which cause the two kinds of scab. Common scab is due to a parasite (*Oospora scabies*) of very minute, threadlike form, now considered to be more related to the bacteria than to the filamentous fungi. Powdery scab is due to a slime mold (*Spongospora subterranea*), a relative of the cabbage clubroot organism. Its spore balls appear under the microscope as large balls characteristically marked and easily recognized.

Osborn holds that the soil moisture determines to a great extent the damage done by the disease. Under dry conditions of the soil the external appearance is limited to small circular patches about 5 mm. across. Under wet conditions the damage is more serious and the scabs may be as large as 3 to 4 cm. in diameter and as much as 2 cm. in depth.

Powdery scab is common in northern Europe, where it has been known for many years. In Canada it occurs in the provinces of New Brunswick, Prince Edward Island, Nova Scotia, and Quebec, not universally but rather generally distributed in many sections. The disease appears not to be established in the United States except in isolated cases, mostly near the Canadian border, where further surveys are now being made. There is need for the continuance of careful surveys in all States where any imported potatoes may have been planted, to insure the stamping out of any infection that may be present.

POWDERY SCAB IN IMPORTED POTATOES.

Very little is known of the extent to which powdery scab was present in potatoes brought from Europe prior to 1912. In October, 1913, in response to market demands, large shipments of potatoes began to come in from the Netherlands, Belgium, and Denmark, as well as from Canada. Examinations of these potatoes at the ports of New

¹ Cf. Melhus, I. E., Powdery scab (*Spongospora subterranea*) of potatoes, U. S. Department of Agriculture, Bulletin 82, 1914. This publication contains a full description of the disease and the causal parasite.

York and Boston by departmental inspectors showed the presence of powdery scab in most of the arrivals from the Netherlands and in many of those from Belgium and Canada. The percentage of powdery scab varied from a trace up to 20 per cent or more. The scab was usually of the superficial type, though some advanced cases were found. Common scab was also present.

It has been suggested since by the representatives of the Governments of the Netherlands and Belgium that these infected potatoes may have originated in Germany rather than in their countries, and an examination of the situation has indicated that the original quarantine order may not have provided sufficient safeguards against the transshipment of potatoes from Germany and other quarantined countries through Antwerp, Rotterdam, and other nonquarantined ports.

In the situation thus presented, the Department of Agriculture had to determine promptly two points: (1) Is there danger that diseases present on imported potatoes will become established in American fields? (2) Is the powdery scab a new and dangerous disease requiring exclusion by quarantine?

POSSIBLE INFECTION FROM IMPORTED POTATOES.

The greater portion of the foreign potatoes imported are intended for table purposes and are consumed in New York, Boston, and Philadelphia, where it has been urged that by no possibility could infection reach potato fields. The facts, as determined by the Department of Agriculture, are that hundreds of thousands of bushels have been shipped from New York to interior points and that foreign potatoes have been sold as far west as St. Louis and as far south as New Orleans. This was particularly the case in 1911. There are abundant opportunities for disease germs on potatoes used for food to reach the land. Partially decayed or scabby tubers are sorted out by the retailers and disposed of for feeding to live stock, and manure thus infected is hauled to surrounding farms. Parings from the potatoes go into the family garbage can and find their way directly or indirectly to cultivated fields.

A second avenue of infection is through the use of foreign potatoes for seed. It is now fairly well known that European varieties do not succeed in the United States and that the use of foreign seed is not profitable, yet the number of actual instances traced by the Department of Agriculture where European seed potatoes were purposely planted as an experiment or through ignorance of their lack of value, or where unscrupulous dealers had sold foreign stock as domestic, is large enough to show that the danger from this source is a real one. Canadian potatoes are valued for seed purposes and were being bought in large quantities when the quarantine was laid.

The use of foreign sacks which had contained infected potatoes is a third means of spreading disease to American potatoes. Great numbers of these sacks are gathered up through secondhand dealers and sold in New York, Maine, and other producing centers for use in shipping domestic potatoes. It has not been the practice to sterilize these sacks, though a treatment with steam would render them safe.

The conclusion reached after consideration of the possibility of the spread of disease through garbage, seed potatoes, and reused sacks was that it will be impossible to prevent the permanent establishment in the United States of any parasitic disease common on imported potatoes.

IS THE POWDERY SCAB DANGEROUS?

The Federal Horticultural Board was compelled to decide promptly whether the best policy for the country would be to treat powdery scab as a disease of minor importance and make no restrictions on importations from infected countries, recognizing as inevitable that the disease would soon become common and widely distributed in the United States, or whether it should be considered sufficiently dangerous to warrant exclusion measures. In deciding this important point all available information was secured. Advice was sought from the plant pathologists in the several State experiment stations, all foreign publications on the subject were consulted, and the advice of representatives of foreign governments was taken through correspondence and at a public hearing held in conformity with the plant quarantine act on December 18, 1913. This hearing was attended by a large number of plant pathologists and other State officials, by representatives of farmers' organizations and commercial bodies, and by interested individuals. The thousands of letters, petitions, and telegrams received by the board showed that the potato growers of the country are no longer apathetic on the question of potato diseases.

The advice of the foreign representatives was to the general effect that European potatoes had been imported in large quantities for many years; consequently, that if powdery scab were communicable it must be common in the United States, but overlooked, in which event a quarantine would not be lawful under the plant quarantine act. Further, that if powdery scab had not already become established, this fact should be considered as evidence that no danger exists.

It was also represented that powdery scab is a disease of such minor importance that the interruption of trade by a quarantine was not justified, and that, if introduced, it could be controlled by using no infected tubers for planting and by discontinuing the use of infected land for growing potatoes. The evidence on each of these points and on other phases considered is summarized later.

OCCURRENCE IN THE UNITED STATES.

During the past two years the pathologists of the Department of Agriculture have visited every important potato section to look for powdery scab and other diseases. Potatoes in the large markets have been examined, the Plant-Disease Survey collaborators in the several States have been asked to be on the watch for powdery scab, and the State of Maine has been given special attention by both the department and the State experiment station.

Outside of the State of Maine no definite cases have been traced to farms, but some evidence of powdery-scab infection was found by Dr. Morse, of the Maine experiment station, in two sendings of potatoes from western Nebraska and Massachusetts.

Considerable powdery scab has been found in Maine very recently. This infection is most abundant on the northern border of Aroostook County, but scattered cases occur elsewhere, many of which have been traced directly to seed potatoes brought over from the infected districts of Canada. Thus far only a very small percentage of Maine farms has been found infected.

The State authorities have taken prompt and vigorous action to survey the State in order to locate all infections. An inspection service has been organized, which will issue certificates of freedom from powdery scab, and no potatoes known to be diseased will be allowed to leave the State. Seed stock will be examined with special care.

It is believed that these measures will provide an adequate safeguard against the future spread of powdery scab to other States. The State of Maine expects to quarantine all infected fields and will endeavor to stamp out the disease.

A more thorough survey of other States is now under way. The evidence is very strong that at the present time powdery scab is not "widely distributed in the United States."

LIKELIHOOD OF SPREAD.

That the disease has not already gained a greater foothold in spite of numerous importations is perhaps the strongest argument advanced by the opponents of a quarantine. This is probably a matter of good fortune rather than proof of noncommunicability. The contrary evidence includes its apparent general occurrence in certain foreign districts, the fact reported by Dr. Melhus that in Canada those sections which use European varieties and which often import seed are more infected than those using seed from American sources, and the experimental evidence secured by Dr. Morse in Maine and by Irish workers that the disease is readily communicable by planting infected seed potatoes.

RELATIVE IMPORTANCE IN EUROPE AND THE UNITED STATES.

Powdery scab has been in the past a minor potato disease in Europe; that is to say, it has not been recognized by the public as a serious trouble, nor has it engaged the time and attention of scientific investigators to the extent that other potato diseases, such as leaf-roll, have. Recent publications by Johnson and by Pethybridge, the leading plant pathologists of Ireland, lead to the conclusion that the disease is more serious there than has previously been realized, particularly in gardens and fields continuously cropped in potatoes, where it tends to assume the cankerous stage and reduces the market value of the potatoes for eating purposes. It may well be that powdery scab is becoming more serious in Europe. Johnson states:

I have no doubt myself that *Spongospora* scab has a good deal to do with the miserable average yield per acre of potatoes in the west of Ireland. * * * It is in some districts of Ireland as injurious to potatoes as finger-and-toe is to turnips.

DIFFERENCES IN MARKET STANDARDS.

An important consideration in this connection is that any scab or other disfigurement of the tuber reduces its market value much more in the United States than in Europe. The consumer abroad does not object seriously to a scabby potato. In fact, we are assured by our English visitors that it is a general belief in Great Britain that scab is an indication of good quality for eating purposes. In the United States, however, scabby potatoes are rejected for market purposes. In Maine they were sorted out and sold to the starch factory for 50 cents per barrel as compared with \$1.50 which they would have brought if clean. In communities where there are no starch factories the scabby potatoes are fed to stock or left lying in the field. As a consequence, scab-infected fields are worthless for potato growing and their market value is greatly impaired.

SCAB DISEASES WORSE IN THE UNITED STATES THAN IN EUROPE.

Powdery scab has not occurred in the United States to an extent that permits any comparison of its virulence here with its behavior in Europe. It is, however, a well-known fact that introduced troubles as a class are more destructive than in the country of origin, owing to differences in climate or other conditions. The several important potato districts of the United States—Maine, New York, the trucking districts of the Atlantic seaboard, the northern Great Lake district, the Red River Valley, Colorado, Idaho, Oregon, California, etc.—differ exceedingly in soil and climate, and there is reason to fear that powdery scab might find in one or several of these districts conditions much more favorable than exist in Europe and that it would assume a more virulent form.

It is certain that our common scab is much more common and disfiguring throughout the United States than it is in Europe, and the injuries caused by the fungus *Rhizoctonia* to potatoes in the West are greater than any reported from Europe.

COMPARISON OF POWDERY-SCAB INJURIES.

Common scab produces a roughened spot or pockmark on the tuber, which in its worst stage may cover the whole potato. Underneath the scab spots, however, a cork layer is formed and the potato remains sound. It is not more subject to decay than other potatoes, and the actual injury from a food standpoint is due to the greater loss in peeling before cooking.

Powdery scab in its milder form causes no greater outward disfiguration than common scab, but there is less of a cork layer formed and a progressive decay frequently follows. The cankerous stage of powdery scab is more objectionable than any phase of common scab and is as bad as the wart disease. Finally, no means of controlling powdery scab through the disinfection of seed potatoes, as practiced for common scab, has proved wholly satisfactory.

All these considerations led the Department of Agriculture to the conclusion that measures for preventing the introduction of powdery scab into the United States were not only fully justified, but were demanded by every rule of prudence and precaution.

Most foreign countries have long since wisely adopted a similar procedure with reference to American potatoes, mainly on account of the Colorado potato beetle. Canada maintains a complete embargo against all European countries, and most of the English colonies restrict the importation of potatoes to a greater or less extent on account of the wart disease and other troubles.

OTHER REASONS FOR POTATO REGULATIONS.

Experience gained in the enforcement of the potato quarantine order of September 20, 1912, and further investigations of potato diseases and insect enemies have shown that more efficient and logical means are required for the adequate protection of this country against the potato parasites of the world.

Where a quarantine is laid against a whole country on account of an infection limited to a small portion of that country, the justice of the act is questioned by residents of the disease-free districts, yet there has been no means of limiting quarantines by other than national boundaries except through the active cooperation of the foreign government.

Where a quarantine is laid against one country and not against another concerning a commodity like potatoes, which is a staple ar-

ticle of trade between the two nations, it is very difficult to prevent transshipments from the quarantined country through the ports of the nonquarantined country unless special measures are taken by the governments concerned to regulate such trade.

Finally, it is impossible to foresee all the conditions that will arise in the course of international commerce. Shipments come from new sources and may bring parasites hitherto unknown to which existing regulations may not apply. An example is afforded by some small importations of potatoes from South America in 1913, which were found infested with new species of weevils, more dangerous than any previously known, which tunnel through the tuber and destroy its value without greatly impairing its appearance.¹ This finding emphasizes the necessity of maintaining a careful watch over all potatoes coming from South or Central American sources. Effective regulations are therefore to be preferred to quarantines, in order to permit the most complete protection against the introduction of parasites without hampering trade more than is necessary.

A step in this direction has been taken by the issuance of the following order applying to potatoes the provisions of the nursery stock regulations, under the plant quarantine act:

UNITED STATES DEPARTMENT OF AGRICULTURE,
OFFICE OF THE SECRETARY,
FEDERAL HORTICULTURAL BOARD.

ORDER COVERING ADMISSION OF FOREIGN POTATOES UNDER RESTRICTION.

The Secretary of Agriculture has determined that the unrestricted importation from any foreign country of the common or Irish potato grown in the Dominion of Canada, Newfoundland, Great Britain, Ireland, Continental Europe, and other foreign countries may result in the entry into the United States, its Territories and Districts, of injurious potato diseases, including the powdery scab (*Spongospora subterranea*), and injurious insect pests.

Now, therefore, I, DAVID F. HOUSTON, Secretary of Agriculture, under authority conferred by section 5 of the act of Congress approved August 20, 1912, known as "The Plant Quarantine Act" (37 United States Statutes at Large, page 315), do hereby determine and declare that on and after January 15, 1914, common or Irish potatoes imported or offered for import into the United States or any of its Territories or Districts shall be subject to all the provisions of sections 1, 2, 3, and 4 of said act of Congress.

Done at Washington this 22d day of December, 1913.

Witness my hand and the seal of the United States Department of Agriculture.

[SEAL.]

DAVID F. HOUSTON,
Secretary of Agriculture.

¹ Pierce, W. Dwight. Journal of Agricultural Research, vol. 1, no. 4, p. 347-352, pl. 3, 1914.

Pending the completion of arrangements with foreign governments for the survey and delimitation of disease-free districts and for the inauguration of a system of inspection and certification of potatoes, a temporary quarantine was laid, as follows:

UNITED STATES DEPARTMENT OF AGRICULTURE,
OFFICE OF THE SECRETARY,
FEDERAL HORTICULTURAL BOARD.

NOTICE OF QUARANTINE NO. 11 (FOREIGN).

POTATO QUARANTINE.

The fact has been determined by the Secretary of Agriculture that injurious potato diseases, including the powdery scab (*Spongospora subterranea*), new to and not heretofore widely prevalent or distributed within and throughout the United States, exist in the Dominion of Canada, Newfoundland, the islands of St. Pierre and Miquelon, Great Britain, Ireland, and Continental Europe, and are coming to the United States with imported potatoes.

Now, therefore, I, DAVID F. HOUSTON, Secretary of Agriculture, under the authority conferred by section 7 of the act of Congress approved August 20, 1912, known as "The Plant Quarantine Act" (37 United States Statutes at Large, page 315), do hereby declare that it is necessary, in order to prevent the introduction into the United States of such potato diseases, to forbid the importation into the United States, from the countries hereinbefore named, of the common or Irish potato (*Solanum tuberosum*) until such time as it shall have been ascertained, to the satisfaction of the Secretary of Agriculture, that the country or locality from which potatoes are offered for import is free from such potato diseases.

On and after December 24, 1913, and until further notice, by virtue of said section 7 of the act of Congress approved August 20, 1912, the importation, from the countries hereinbefore named, of the common or Irish potato, except for experimental or scientific purposes by the Department of Agriculture, is prohibited: *Provided*, That shipments of such potatoes loaded prior to December 24, 1913, as shown by consular invoices, will be permitted entry up to and including January 15, 1914.

Done at Washington this 22d day of December, 1913.

Witness my hand and the seal of the United States Department of Agriculture.

[SEAL.]

DAVID F. HOUSTON,
Secretary of Agriculture.

A GENERAL QUARANTINE NOW IN EFFECT.

The order quoted above has resulted in the stoppage of potato importations from Canada and all the countries of Europe for an indefinite period. It is not known at present how many of these countries will ultimately qualify for the lifting of the quarantine, but the apparent general distribution of powdery scab in many of them makes it improbable that they will resume shipments to the United States in the near future. Certain portions of Canada are reported to be nearly free from powdery scab, and the vigorous campaign now being waged there against the disease offers hope that the restriction may be modified with respect to specified districts at an early date.

The initiative in lifting the quarantine rests with the foreign government, which must notify the United States that specified dis-

tracts have been surveyed and found to be free from wart and powdery scab and that they are ready to inspect and certify potatoes intended for export, in conformity with our regulations.

Such action has now been taken by the Kingdoms of Belgium and Denmark, and on February 20, 1914, the quarantine was lifted from these countries by an order of the Secretary of Agriculture, and hereafter their potatoes may be imported into the United States subject to and in accordance with the general regulations referred to. These regulations have been issued in printed form, and all persons desiring full details, especially as to the procedure to be followed in making importations, should procure an official copy.¹

GENERAL EXPLANATION OF REGULATIONS.

Control of importations is secured through a system of permits, as already in force for nursery stock. The importer makes his application to the Federal Horticultural Board at Washington, on forms provided, and receives a permit authorizing him to import potatoes from a specified firm and district from the time of issuance until June 30 following. A permit for each shipment is not required. Notice must be given to the board when each shipment arrives. For details, the regulations should be consulted.

IMPORTATIONS ALLOWED FROM DISEASE-FREE DISTRICTS ONLY.

The regulations provide that before the quarantine is lifted or permits are granted for importations from any country the officials of that country shall determine by a field survey, or in the case of the present crop by a cellar or pit inspection, that the country or district is entirely free from wart and powdery scab.

It is not intended that there shall be any attempt made to separate by sorting the clean from the infected potatoes. The warning has been emphatic from all pathologists consulted that such an inspection would be utterly impracticable; that if any disease was present in a lot of potatoes it would be out of the question to sort them under commercial conditions without overlooking some disease. Infection might also be carried on healthy potatoes that had been in contact with diseased tubers.

It is believed by the Federal Horticultural Board that the freedom of a district from disease can be determined with sufficient accuracy to afford a reasonable safeguard when checked by the foreign inspection and by inspection on arrival at the port of entry.

Prevention of transshipments from quarantined districts is accomplished through the cooperation of the foreign government, which must provide an "effective quarantine" against districts quarantined

¹ Regulations governing the importation of potatoes into the United States under the provisions of the order of the Secretary of Agriculture issued December 22, 1913.

by the United States. This may be done by a decree prohibiting the exportation to the United States of potatoes not grown in the country taking the action.

CERTIFICATE OF INSPECTION.

No potatoes are to be admitted to the United States under the new regulations unless they are accompanied by a certificate issued by an official authorized of the country of origin, stating that they were grown in a specified disease-free district or locality, that they have been inspected by him and found free from dangerous insects and plant diseases, and that they are packed in containers that have never been used for potatoes. An original certificate of this nature must accompany the invoice when presented at the customs office, and a copy of the certificate must be attached to each sack, barrel, or other container. Provision is made for bulk carload shipments, but not as yet for wagonloads hauled across the border.

INSPECTION ON ARRIVAL.

Shipments will not be released from customs until inspected by a representative of the Federal Horticultural Board and found free from dangerous diseases. If powdery scab or wart is discovered the shipment must be exported or destroyed.

The most important safeguard provided is the limitation of imports to potatoes grown in disease-free districts or countries and the foreign inspection and certification. The port of entry inspection in the United States serves as a check on these, but is not a sufficient means in itself, for the reasons already stated and because only a portion of each shipment can be carefully looked over without maintaining an army of inspectors.

LIMITATION OF PORTS OF ENTRY.

The right is reserved under the new regulations to restrict importations of potatoes to ports of entry named by the Federal Horticultural Board when the permit is granted. It is manifestly impossible to maintain an inspection service at each customs office, and at the outset it is probable that entries will be allowed regularly only at New York and Boston, with the exception of special cases where it proves feasible to have inspections made elsewhere. By far the greater part of the potatoes imported in past years have come to the port of New York. Permits must be secured in advance of importation in all cases.

ADDITIONAL SAFEGUARDS.

If inspection at the port of entry shows that potatoes are infected with the wart disease or with powdery scab or other injurious plant diseases, or with injurious insect pests, the shipments will be refused

entry. Permits for the entry of potatoes may be refused and existing permits may be canceled on proof that the certificate of inspection does not correctly give the locality where the potatoes were grown, the character of the shipment as to freedom from disease or insect infestation, or falsely states that the containers have not been previously used for the shipment of potatoes.

Permits may be canceled and further permits refused for the importation of potatoes from any country whenever such potatoes, in the judgment of the Federal Horticultural Board, are found to be so infected as to indicate plainly that the foreign inspection is merely perfunctory, or if the permittee fails to give to the Secretary of Agriculture and to the duly-authorized inspector of the department at the port of entry designated in the permit notices of the arrival of potatoes or gives a false notice.

IMPORTATIONS FROM NONQUARANTINED COUNTRIES.

Potatoes will be allowed to enter from sources other than Canada and the countries of Europe when properly inspected and certified by the authorized officials of the country of origin. The importers must comply with the permit requirements already mentioned.

Bermuda has complied fully with the regulations by prohibiting the importation of potatoes from Canada and Europe and by inaugurating a rigid inspection service. The importation of potatoes from these islands has therefore continued without check.

The total quantity of potatoes brought from Bermuda during the year ended June 30, 1913, was 141,422 bushels. These are all entered at New York and find a special market at a high price. None are used for planting in the United States.

The importation of potatoes from the State of Chihuahua, in Mexico, having been determined by an inspector of the Department of Agriculture to be attended by no risk from insects or diseases, the requirement of foreign certification has been waived temporarily in consideration of existing conditions in Mexico, and permits are being granted for such importations, from Chihuahua only, subject to inspection at El Paso, Tex., the port of entry.

Last year's importations from Mexico amounted to 8,301 bushels.

RELATION OF IMPORTED TO DOMESTIC POTATOES.

The total imports of potatoes into the United States make up a very small proportion of the total consumption, as may be computed from Table I. For the five years, 1907-1911, preceding the quarantine, the imports minus the exports were 1.03 per cent of the estimated production.

TABLE I.—*Acreage, production, value, prices, exports, and imports of potatoes in the United States, 1900 to 1912, inclusive.*

Year.	Acreage planted and harvested.	Average yield per acre.	Production.	Average farm price per bushel, Dec. 1.	Farm value, Dec. 1.	For fiscal year beginning July 1.	
						Domestic exports.	Imports.
		<i>Bushels.</i>	<i>Bushels.</i>	<i>Cents.</i>		<i>Bushels.</i>	<i>Bushels.</i>
1900.....	2,611,000	80.8	210,927,000	43.1	\$90,811,000	741,483	371,911
1901.....	2,864,000	65.5	187,598,000	76.7	143,979,000	528,484	7,656,162
1902.....	2,966,000	96	284,633,000	47.1	134,111,000	843,075	358,505
1903.....	2,917,000	84.7	247,128,000	61.4	151,638,000	484,042	3,166,581
1904.....	3,016,000	110.4	332,830,000	45.3	150,673,000	1,163,270	181,199
1905.....	2,997,000	87	260,741,000	61.7	160,821,000	1,000,326	1,984,160
1906.....	3,013,000	102.2	308,038,000	51.1	157,547,000	1,530,461	176,917
1907.....	3,128,000	95.4	298,262,000	61.8	184,184,000	1,203,894	403,952
1908.....	3,257,000	85.7	278,985,000	70.6	197,039,000	763,651	8,383,966
1909.....	3,525,000	106.8	376,537,000	54.9	206,545,000	999,476	353,208
1910.....	3,720,000	93.8	349,032,000	55.7	194,566,000	2,383,887	216,984
1911.....	3,619,000	80.9	292,737,000	79.9	233,778,000	1,237,276	13,734,695
1912.....	3,711,000	113.3	420,647,000	50.5	212,550,000	.....	.....

THE 1913 POTATO CROP.

The potato crop of the United States for 1913 is estimated to be 238,946,000 bushels. The principal shortage is in the Central States, which are not the leading potato States. Comparisons to determine the actual needs of the country can not fairly be made with the 1912 crop, which was so large that hundreds of thousands of bushels went to waste for lack of a market and millions of bushels were sold for less than the cost of production.

The following is quoted from the department's Weekly News Letter to Crop Correspondents, January 28, 1914:

FIRMER HOLDING OF POTATOES BY THE FARMERS.

SUPPLY IS NEARLY NORMAL, BUT DISTRIBUTION IS UNUSUALLY UNEVEN—PRINCIPAL POTATO-PRODUCING STATES HOLD SUPPLIES, WITH SHORTAGE IN A NUMBER OF CONSUMING STATES.

The yearly estimates of the amount of potatoes remaining in growers' hands and the stocks in dealers' hands on January 1 in the important potato States, just completed by the Bureau of Statistics (Agricultural Forecasts), United States Department of Agriculture, indicate that a larger proportion of the marketable crop of potatoes was still in the hands of farmers on January 1 than had been the case for four years past. The proportion estimated to be in dealers' hands was smaller than for any year of the four except January 1, 1912. The figures showed that the total estimated potato production was below normal, but, owing to the slow movement of the crop up to January 1, the supply for the remainder of the year will be almost normal. Distribution, however, seems to be unusually uneven. The holdings of potatoes are relatively large in the important producing States of Maine, Michigan, Wisconsin, and Minnesota; and relatively small in New York, Ohio, Indiana, Illinois, Iowa, and Kansas, which are important both as potato-producing and potato-consuming States.

In consequence of the firm holding by farmers the price early in the season has been unusually high, being on December 1 about 17½ cents per bushel higher than

a year ago and 16½ cents higher than three years ago, but 11½ cents lower than two years ago, when potatoes on January 1 were selling for 77½ cents per bushel and the supply was unusually short, owing to the drought of the previous year.

Present conditions do not seem to forecast material, if any, advance in prices in the important producing States this year. In 1911, when supplies were but moderately larger than now, and in 1913 the price movement after January 1 was downward instead of upward. The only other factor which may enter to change the experience of 1911 and 1913 is the somewhat different distribution of the crop which exists this year.

Southern growers who plant in the spring for the early market would seem to be justified, from present conditions, in putting out a normal acreage, but should not expect the big advance in prices which prevailed two years ago.

The estimates indicate that about 42.1 per cent of the marketable supply of potatoes of the 1913 crop remained in the hands of farmers and 9.5 per cent in the hands of dealers on January 1 in the important potato-growing States. These figures compare with 39.8 and 9.8 per cent similarly estimated a year ago, 33.1 and 8.6 per cent two years ago, 40.2 and 10.9 per cent three years ago, and 41.2 and 9.9 per cent four years ago. If, for the purpose of comparison, these percentages were applied to the estimates of total production, it would show total stocks of 123,000,000 bushels on January 1, 1914 (in the 19 States analyzed below), compared with 150,000,000 a year ago, 91,000,000 two years ago, 133,000,000 three years ago, and 142,000,000 four years ago. These figures would indicate that the quantity to be carried toward the close of the season will not be sufficient to cause depressed prices, as was the case particularly four years ago (in some States last year, also), nor, on the other hand, will they be so scant as to cause such high prices as prevailed in the spring of 1912.

To show the relation between supplies and prices, the following tabulation is given, showing for the past five years the production, stock on hand January 1, and the prices paid to producers on December 1 and the following March 1 in 19 important potato-growing States:

Years.	Total production (bushels).	Stocks on Jan. 1.					Farm prices.	
		In growers' hands.		In dealers' hands.		Total (bushels).	Dec. 1.	Mar. 1.
		Per cent of crop.	Bushels.	Per cent of crop.	Bushels.			
1913-14.....	238,946,000	42.1	100,495,000	9.5	22,797,000	123,292,000	66.2	-----
1912-13.....	304,126,000	39.8	119,678,000	9.8	30,167,000	149,845,000	48.6	47.7
1911-12.....	217,532,000	33.1	72,072,000	8.6	18,706,000	90,778,000	77.6	101.4
1910-11.....	261,141,000	40.2	104,954,000	10.9	28,463,000	133,417,000	49.5	46.9
1909-10.....	298,308,000	41.2	122,997,000	9.9	29,384,000	142,381,000	50.0	47.3

A PROGRESSIVE POLICY NEEDED.

The present situation emphasizes the fact that potato production in the United States is not on a sound economic basis. We have an almost regular alternation of seasons when more potatoes are produced than can be consumed and prices fall below production costs in many instances and of seasons of short crops when prices are unreasonably high to the consumer. This condition is reflected in the imports and exports, as shown in figure 1.

It will be noted that during seven years of the twelve, more potatoes were exported than were imported, while during five years the imports exceeded the exports.

The possibilities of potato production in the United States are almost unlimited. All of the States could increase their acreage and their average yield, and there exist in many northern districts, particularly in Maine, Michigan, Wisconsin, and Minnesota, large areas of cut-over lands, recently in forest but now being brought under cultivation, which could produce many times more potatoes than at present. The same is true of the irrigated West. Under present economic conditions, however, no material increases in acreage could be made without risk of overproduction.

Among the most striking features of potato culture in the United States are the low average yield per acre, the relatively high cost of production per bushel, the distance from markets of many important

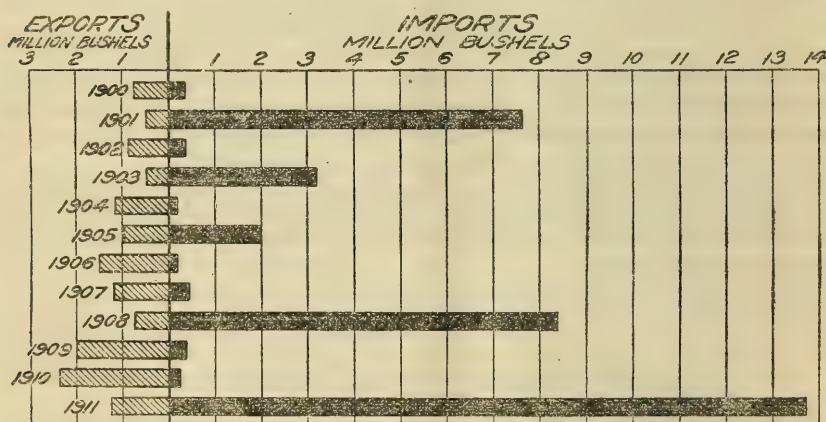


FIG. 1.—Exports and imports of potatoes for the United States during the years 1900 to 1911, inclusive, showing graphically the alternating seasons of overproduction and scarcity.

potato districts, and the fluctuations in the market price, which make potato growing rather a speculative enterprise.

To insure permanent prosperity there is a real need for the adoption of a constructive policy that will strike at the roots of the present difficulties, a policy of which quarantines or the regulation of imports are only minor phases, for foreign potatoes must of necessity in the future play a still smaller rôle than now in supplying food to the people of the United States as our population increases and as the European crop will be more and more needed for home consumption.

PROTECTION FROM DISEASE.

In view of the already excessive losses from diseases and insects, it is apparent that it is of national importance to prevent the introduction of more pests of this nature from other countries, a protection which is afforded through the plant quarantine act.

The quarantine law is, however, not the best means of controlling diseases already existent within our borders, for it does not provide authority for quarantining a single farm or a limited district in one of the States except as to interstate shipments. It is, therefore, of the highest importance that each State enact legislation authorizing the proper State officials to search for suspected cases of new or dangerous diseases and empowering them in the event of their discovery within the State to destroy infected stock or material, to put under quarantine the areas involved, and to take other measures needed to prevent the spread of the trouble. In some States such laws exist for nursery stock, but they do not always cover potatoes. It is particularly in States doing a large business in seed potatoes that such legislation is needed.

The fact that many diseases, like the black-leg, dry-rot, scab, and eelworm, are scattered far and wide on infected seed also makes necessary some community or State action to control these troubles at the source by stimulating the growing of seed potatoes as a special business and by establishing a system of inspection and certification that will provide a means by which distant purchasers can be guaranteed the freedom from disease of potato seed stock purchased, as well as its varietal purity and vigor.

At present, the consumer shares the loss from potato diseases, whether in the field, in storage, or en route to market. Much of the loss can be prevented by better spraying or better methods of grading, handling, and shipping, which have not yet been worked out and adopted on account of a lack of concerted action and community of interest on the part of buyers, shippers, jobbers, and retailers. These men can assist the grower in lowering the present excessive retail prices of potatoes.

LACK OF AN OUTLET FOR SURPLUS POTATOES.

Under present conditions the production of potatoes is limited by the requirements of the market for table stock. A few culls are made into starch and a few fed to stock, but there is no extensive use of potatoes for industrial purposes such as one finds in Europe.¹

Furthermore, the production in the United States is greatly influenced by weather conditions, especially by the occasional periods of heat or drought to which we are more subject than Europe and to which the potato is more sensitive than some other crops.

The result is that when we add to these two factors the natural tendency of farmers to reduce their acreage after a year of low prices and to increase it after a year of high prices, we have the excessive fluctuation in supply and market prices already described.

¹ Cf. Department of Agriculture, Bulletin 47.

Some means of disposing of surplus potatoes is an economic necessity. If this can be done at a price reasonably above the cost of production, the potato crop will increase and a reserve supply of potatoes grown for industrial uses will be established that will meet the needs of all short years.

Diversification or the introduction of better farming systems will be a step in this direction. Means should be worked out for keeping more live stock, especially swine, on potato farms, and a better understanding of the feeding value of potatoes and of the best rations combining potatoes with other feeds should be secured.

The industrial uses of potatoes for starch, dextrin, alcohol, etc., require investigation in the United States. Perhaps the most pressing need along this line is the adaptation of a method of drying potatoes, as practiced in Germany, to American conditions, to the end that surplus quantities and culls of this perishable product may be preserved and by removal of its water rendered transportable to market. This problem is closely connected with that of varieties, for the starch content of most American potatoes is low, often too low for profitable drying. Breeding for higher starch content needs to be promoted, as well as breeding for table quality, productivity, and disease resistance.

A nation-wide cooperation for the solution of these different phases of the potato question should not leave out of consideration the problem of values from a national viewpoint: That the cost of producing and distributing potatoes should be kept down to such a point that the market price of this staple food shall be comparable with other staples. Marketing investigations and related problems of distribution demand active support.





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Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
April 6, 1914.

(PROFESSIONAL PAPER.)

POWDERY SCAB (*SPONGOSPORA SUBTERRANEA*) OF POTATOES.¹

By I. E. MELHUS,

Pathologist, Cotton and Truck Disease and Sugar-Plant Investigations.

INTRODUCTION.

The comparatively recent discovery of *Spongospora subterranea* in the United States makes it necessary to introduce to the potato grower, importer, and pathologist a new potato disease. This disease is commonly known as powdery scab, and mild attacks of it resemble superficially the common *Oospora* scab. Its prevalence in many European countries and the Dominion of Canada has prompted the Secretary of Agriculture to extend, for a time at least, the present quarantine on foreign potatoes.

Although powdery scab has probably been known to exist in Europe since 1841, it was not until within the last decade that it assumed an important rôle in pathological literature. It has been most extensively studied by pathologists in the British Isles, where powdery scab is said to be very common.

In February, 1913, *Spongospora* was reported for the first time in North America. It was collected in several provinces of Canada by the Dominion Botanist, Dr. H. T. Güssow (1913),² who has expressed the opinion that the first introduction into Canada must have been at least seven years previous. Dr. W. J. Morse (1913), of the Maine Agricultural Experiment Station, and the writer (1913) obtained evidence during the summer of 1913 showing that this disease exists in the United States. It seems probable that it was introduced with the heavy shipments of foreign potatoes in 1911 before the quarantine law against the wart disease went into effect. Sufficient evidence is at hand to show that powdery scab will make inroads on the potato industry unless proper precautions are taken, and it is the

¹ This paper will be of interest to plant pathologists and to potato growers in the northern and southern potato-growing sections.

² The dates in parentheses refer to the bibliography printed at the end of this bulletin.

object of this bulletin to call attention to this fact and ask the concerted effort of all interested in the potato industry to prevent the spread of this malady.

COMMON NAME OF THE DISEASE CAUSED BY SPONGOSPORA.

Spongospora, like many other fungi, has been given a variety of common names. In Germany it was early known as "Kartoffel-räude" (Wallroth, 1842*b*) among the farmers. By Wallroth (1842*a*), who first recorded its occurrence and who considered it a smut, it was given the common name "Knollenbrand." According to Brunchorst it is called "Skorv" in Norway, and is identical with the disease known as "Schorf" or "Grind" in Germany. In the British Isles, where it has been most intensively studied, it has been called corky end, corky scab (Johnson, 1908), powdery scab, Spongospora scab, and potato canker. The name powdery scab, which was first applied to it by Johnson, of Ireland, is in most common use at the present time. This name has reference to a characteristic symptom of the mature spot, or sorus, as it appears when the infected tuber is dug from the ground.

SCIENTIFIC NAME OF POWDERY SCAB.

The scientific name of Spongospora has been changed even more often than its common name. This has probably been due (1) to the imperfect understanding of the life history of the fungus and (2) to the superficial resemblance of the spore balls of Spongospora to those of the smuts. Wallroth (1842*b*), who first collected Spongospora in 1841, named it *Erysibe subterranea*. It was described and figured by Martius (1842) as *Protomyces tubereum solani*. In 1844 Rabenhorst concluded it was not a species of Erysibe and described it in a new genus, *Rhizosporium solani*. That Berkeley (1846) was familiar with the fungus and knew that it had been reported previously is apparent from a short note in one of his articles on the potato murrain published in 1846. He mentions Martius's *Protomyces* and figures the spore balls, choosing, however, to call it *Tubercinia scabies* (Berkeley, 1850). The name of the organism was again changed in 1877 by Fischer von Waldheim, who placed it in another genus and called it *Sorosporium scabies* Berk.

It was not until 1886, when Brunchorst found Spongospora on potatoes in Norway, that it was shifted into the correct group, namely the Myxomycetes. Why Brunchorst failed to recognize or mention any of the earlier descriptions of Spongospora is not explained in his paper. That he was aware of the fact that the same disease existed in Germany and perhaps in England is evident from the following sentence:

Was das Vorkommen des Spongospora betrifft, ist derselbe hier in Norwegen äusserst verbreitet; wenn es sich bestätigen sollte, was ich sicher glaube, dass der

Pilz die Ursache der in Deutschland "Schorf" genannten Krankheit ist, und vielleicht auch der "Scab" der Engländer, würde auch sonst die Verbreitung eine ganz ansehnliche sein.

Nevertheless he described it anew as *Spongospora solani*, and this name was in general use until 1908, when Massee (1908 and 1910) described it as *Spongospora scabies*, combining Brunchorst's generic name and Berkeley's specific name, a combination which is referred to by Pethybridge (1913a) as not necessary and untenable. Johnson, of Ireland, used the name applied by Brunchorst until 1909, when he found evidence to show that Brunchorst's *Spongospora solani* was identical with Wallroth's *Erysibe subterranea*. In an article published in 1911, Horne is unable to confirm Johnson and questions whether the organism described and figured by Wallroth, Martius, and Berkeley really is the same fungus described by Brunchorst. In view of this fact he adheres to Brunchorst's *Spongospora solani*.

In a very recent article Pethybridge (1913a) brings forth still more evidence to establish the identity of Wallroth's *Erysibe subterranea* and the organism now known as *Spongospora*. He also emphasizes the fact "that the question of identity does not rest merely upon the degree of accuracy with which the spore balls are figured, but some regard must also be paid to the very full description given by Wallroth of the development and fate of the warts, which agrees fully with what we know of the behavior of *Spongospora* and which does not apply to any other organism known at present." Judging from the evidence now available as to the specific name of *Spongospora*, it seems clear to the writer that it should be that first used by Johnson, namely, *Spongospora subterranea* (Wallr.) Johnson.

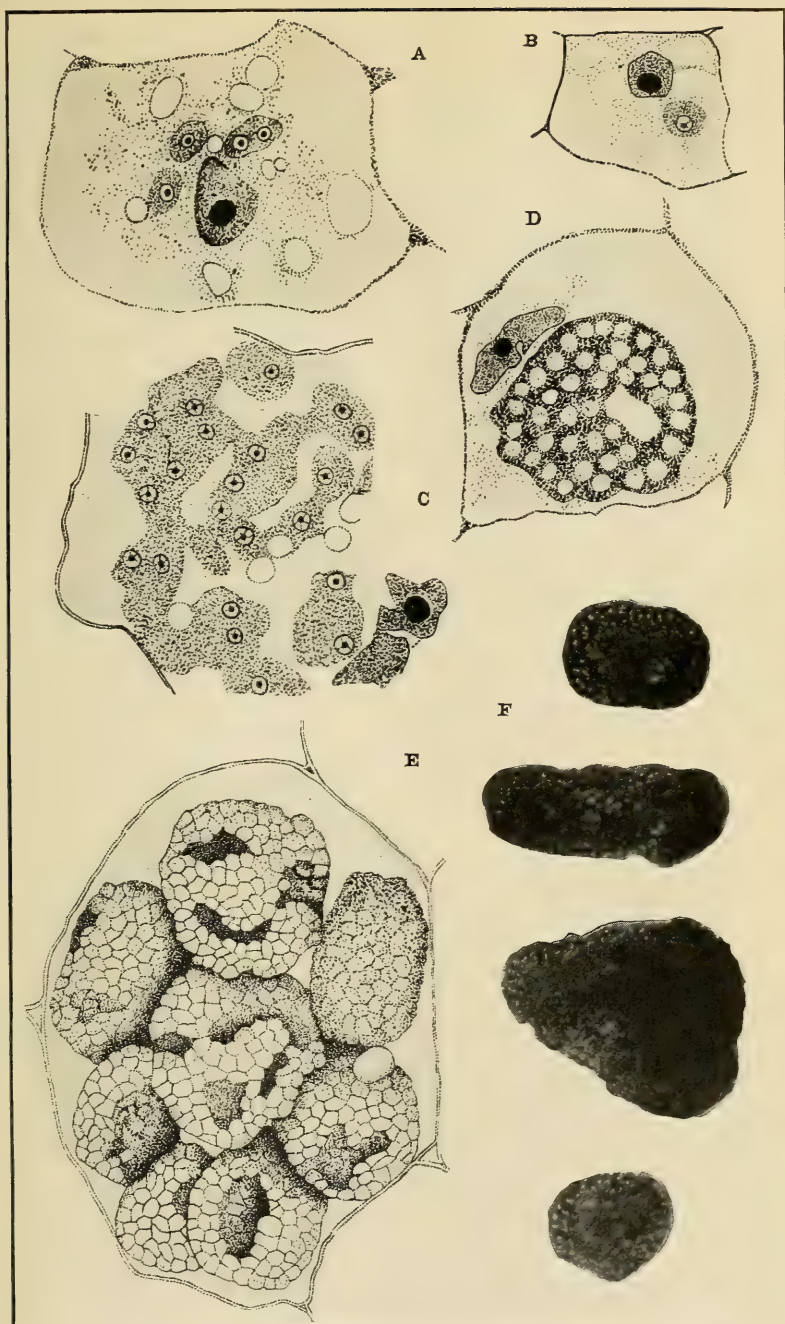
DESCRIPTION OF THE DISEASE.

This disease, so far as is known, never attacks the aboveground portions of the potato plant. It is primarily a disease of the young tubers, which develops as they mature in the ground. The earliest stages of infection, according to Osborn (1911), "are visible on young tubers not larger than hazelnuts. The disease is apparent by small slightly raised pimples and a slight discoloration of the surface. When cut open, the infected areas appear faintly purplish and extend from approximately the outermost cells of the tuber toward the deeper layers. Actual infection of the potato tuber by *Spongospora* has not been seen, nor have infection experiments been successful. The earliest stage in the life history that has been observed is that of a single uninucleate amœba in a young potato cell near the eye." Once in the tissues these naked masses of cytoplasm consume the cell content and multiply rapidly, as shown in Plate I, A, and at the same time stimulate the host cells to further growth and division.

It seems established that the amœbæ pass from one cell to another when cell division takes place, although it is claimed by Massee (1908) that the amœbæ invade new cells by boring through the cell walls. On the other hand, Osborn (1911), who has made an extensive cytological study of this organism, holds that "on the division of the host cell * * * it is a purely fortuitous circumstance whether each resulting cell shall contain an amœba, and so be infected or not. * * * I have never seen any signs of the migration of an amœba to a neighboring cell nor any continuity of protoplasm, such as Massee has described." Osborn's contention as to the method of migration of the amœbæ has been confirmed by Horne (1911). The abnormal local increase of cells causes a swelling and a faint discoloration of the skin, which latter becomes a wartlike outgrowth. The fungus present in this tissue consumes largely the contents of the cells (Pl. I, *C*, *D*), after which the amœbæ coalesce (Pl. I, *C*, *D*) and form one or more large spongy masses in each cell, known as plasmodia (Pl. I, *D*). These latter divide into many small spores, each of which takes on a heavy yellowish brown wall (Pl. I, *E*). Instead of these spores separating, they remain attached, forming a "spongelike body," according to Johnson (1908), and not a hollow sphere, as reported by Berkeley (1846) and Massee (1910).

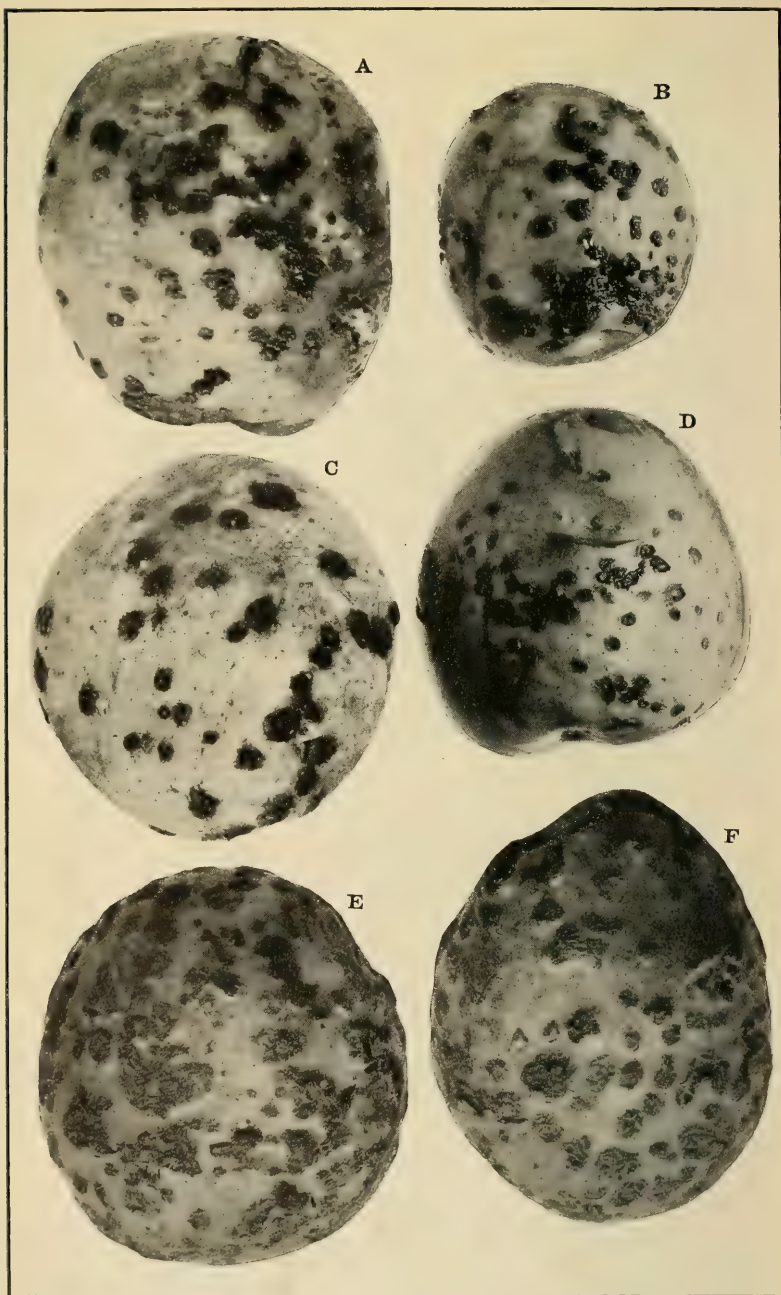
Since the contents of the attacked host cells are used up in forming spore balls, the infected area becomes a pit filled with a yellowish brown dust consisting chiefly of spore balls (Pl. II, *C*). These pits, or sori, at maturity are bordered by the torn skin of the tuber. The torn skin standing up on the periphery of the sorus is one of the characteristics of powdery scab, which often enables one to distinguish it from the Oospora scab macroscopically. The powdery contents of the sori in this stage of the disease doubtless suggested to Johnson the name "powdery scab," as has already been noted. It has been observed that in storage shriveling and shrinkage take place about these pits, or sori. How generally this shriveling occurs and its significance are not known up to the present writing, nor have these matters been emphasized in the literature, to the writer's knowledge. The cause of this shrinkage is not known, but it may possibly be due to insufficient cork deposition in the bottom of the sori which afford an avenue for storage rots to attack the infected tuber.

When conditions are highly favorable for the fungus, it may eat large cavities in the immature tubers. Besides consuming part of the tubers, it stunts their further growth and produces malformed tubers, such as are shown in Plate III. The nature and extent of the depressions caused are shown in Plate III, *C*. This stage of the disease has been called the cankerous stage (Horne, 1911) and is the one that causes the greatest loss.



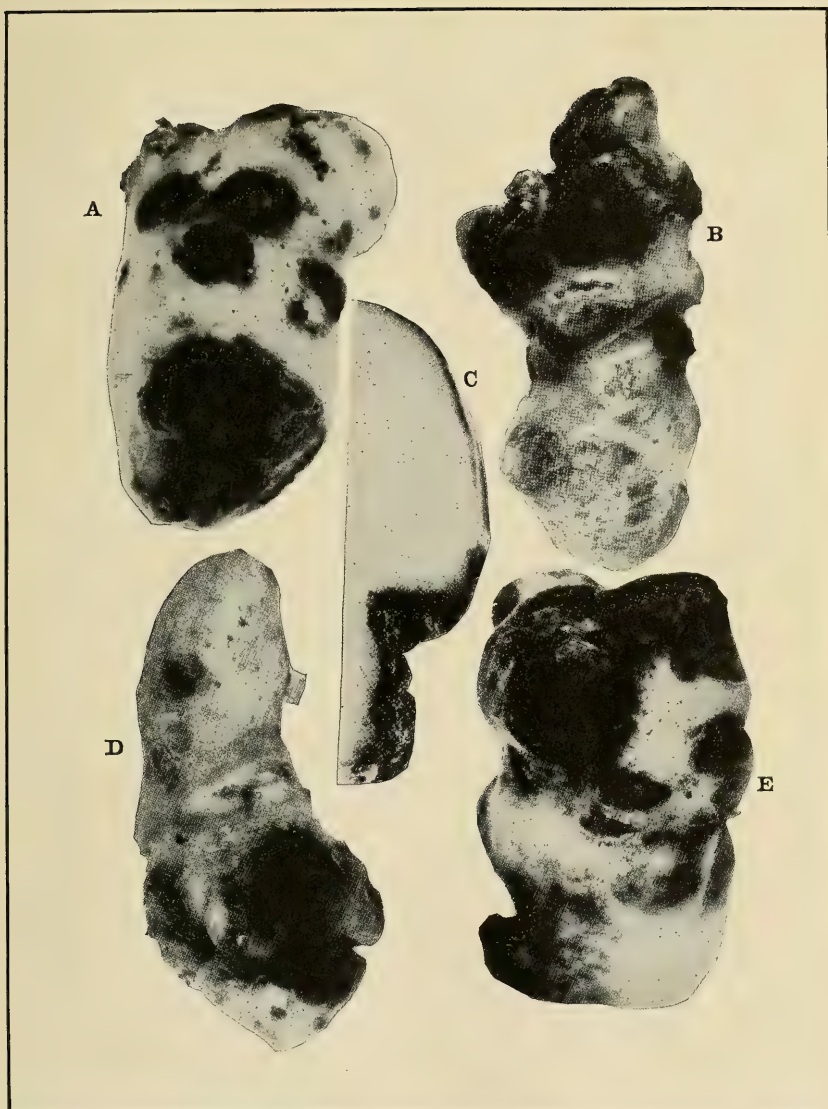
VARIOUS STAGES IN THE LIFE HISTORY OF THE FUNGUS WHICH CAUSES
POWDERY SCAB.

A, A large host cell in which there are three amoebae of *Spongospora*. B, A young host cell in the early stages of infection. The amoeba lies just below the nucleus. C, The amoebae are coalescing to form the plasmodium. D, The plasmodial stage. E, Mature spore balls in an enlarged host cell. (A to E, after Osborn.) F, The isolated spore balls photographed. Note the variation. (Original.)



FOUR TUBERS (A, B, C, AND D) INFECTED WITH *SPONGIOSPORA SUBTERRANEA* COLLECTED IN NEW BRUNSWICK, DOMINION OF CANADA, ON OCTOBER 1, 1913.

They represent the scabby stage of the disease. The sori may be either isolated or grouped, as shown in A and B. The variation in size and general appearance of the sori is brought out in C and D. In the tuber marked D the sori are only about half as large and more superficial than in C. Two tubers infected with *Oospora* scab are shown as E and F.



THE CANKEROUS STAGE OF SPONGOSPORA.

It is this stage that is most destructive to the potato tuber. The cavities and large pustules combine to cause malformation of the tubers. In *C* is shown a section through a tuber badly infected with *Spongospora*. (*A*, *B*, *D*, and *E* are after Horne, *C* after Güssow.)

GEOGRAPHICAL DISTRIBUTION OF POWDERY SCAB.

Spongospora seems to be quite generally distributed in northern Europe. As early as 1841 it was recorded as existing in Germany, and that it had existed for some time before this is suggested by the fact that among farmers the disease had come to be known by a common name (Kartoffelräude). Frank more recently (1897) has mentioned its existence in Germany, but he does not think it is generally distributed. That it does exist to some extent, and possibly more than Frank's report indicates, is suggested by the following facts:

In the spring of 1913 the Bureau of Plant Industry purchased 22 different varieties of seed potatoes from two dealers in Germany. When these were received and examined by the inspecting pathologist, four of the lots were condemned, being infected with *Spongospora*.

In 1846 powdery scab was discovered in England by Berkeley in connection with his studies of the potato murrain, the disease which is now known as *Phytophthora infestans*. The little careful study that was given to *Spongospora* by the pathologists of Berkeley's day may well have been due to the intensive study given to the *Phytophthora* disease, which at that time threatened to destroy the potato industry of northern Europe. The general distribution of *Spongospora* in England and Scotland at the present time can readily be seen from the following statement of the Board of Insect and Fungous Pests for 1909:

It has been reported to the board from many parts of Great Britain, chiefly, however, from those parts where wart disease is also present, or where it has been suspected. Cases have been reported from Peebles, Stornoway, Forfar, Fife, Lanark, Aberdeenshire, Stirlingshire, Lancashire, Cumberland, Shropshire, Rorks, W. W., Staffordshire, Wales, Hereford, Somerset, and Worcester. In Scotland, therefore, the disease seems fairly widely distributed, but in England, as might be expected, it appears to be confined to the west, where the rainfall is higher. It is not, however, to be supposed for a moment that anything like all affected localities are here recorded.

In the spring of the current year the United States Department of Agriculture imported 18 different varieties of potatoes from Scotland for seed purposes, all of which were found to be infected with *Spongospora* and were condemned by the inspecting pathologist. Nine different varieties were imported from England for similar purposes and were not allowed to pass, owing to *Spongospora* infection.

On October 31, 1913, Mr. W. W. Gilbert, of the Bureau of Plant Industry, collected specimens of powdery scab on potatoes imported into this country from the Netherlands. On November 20 the writer likewise collected *Spongospora* at New York City on two different shipments from the Netherlands. The following day specimens were taken by Mr. O. A. Pratt and the writer from a shipment coming from Belgium. More recently the disease has been found several times

in considerable quantity on potatoes coming from the Netherlands and Belgium. As already stated, the disease has been in Norway since 1886 and has since been found in Sweden.

It is also interesting in this connection to note that *Spongospora* occurs in South America, probably the native habitat of the potato. It was collected in 1891 at Quito, Ecuador, by Lagerheim, who reports that the disease is well known to the natives. This suggests two possibilities: (1) That the disease has always existed there or (2) that it was introduced into South America on European varieties.

PRESENCE OF POWDERY SCAB IN CANADA.

More recently powdery scab has gained a foothold in North America, and early in the spring of 1913 it was reported in several Provinces of Canada by Güssow. The writer has been able to confirm Güssow's reports by personally visiting the potato-growing sections in three of the Provinces of Canada, namely, New Brunswick, Prince Edward Island, and Nova Scotia. It was found that powdery scab was quite generally distributed in the lower St. John River valley, New Brunswick, and on Prince Edward Island.

POWDERY SCAB IN THE UNITED STATES.

That *Spongospora* exists also in the United States has been definitely established. In the spring of 1913 Morse, of the Maine Agricultural Experiment Station, obtained some evidence that the disease exists in Nebraska and Massachusetts. No further cases have been reported from these States. In June, 1913, the writer collected 84 tubers infected with *Spongospora* from four barrels of the Green Mountain variety purchased for experimental purposes at Presque Isle, Me. These had been grown in the vicinity of the village during the season of 1912.

Spongospora was collected at Washburn, Me., on February 9, 1914, and at Frenchville on the following day. Later it was found at stations farther south in Aroostook County.

A thorough survey of northern Maine is now being made by the State department of agriculture, with the cooperation of this department. The survey to date indicates that powdery scab is more common in the northern half of Aroostook County. Several cases were found where the growers at some time during the last three or four years had secured seed from the neighboring infested sections of New Brunswick, which may well account for the introduction of the disease. The results secured up to the time this bulletin goes to press indicate that there is considerable powdery-scab infection in Aroostook County. The active measures that are now being taken to discover and delimit the infected areas and to prevent the shipment of diseased potatoes for seed purposes should result in checking the spread of powdery scab.

DAMAGE TO THE POTATO CROP.

The scabby stage of *Spongospora*, like the common *Oospora* scab, is a skin disease confined to the tubers, marring their appearance and thereby decreasing their market value. The cankerous stage, as shown in Plate III, completely destroys the tubers for both food and seed purposes. This observation is confirmed by the following quotation from Pethybridge (1911, p. 442):

As was pointed out last year, *Spongospora* scab presents two forms of attack, in the one case that of small spots on the surface of the tubers, and in the other the form of a "canker" or eating away of the tuber. This latter is, of course, the most serious one, but there are all degrees of transition between it and the spot form.

Pethybridge is inclined to classify the effect on the potato as producing "scab spots" and "cankers," the former doing little harm to the tuber, while the latter, as shown by his illustrations, completely deform and dwarf its growth, so as to make the tubers worthless.

Osborn (1911) holds that the soil moisture determines to a great extent the damage done by the disease and says—

Under dry conditions of the soil the external appearance is limited to small circular patches about 5 mm. across. Under wet conditions the damage is more serious and the scabs may be as large as 3-4 cm. in diameter and as much as 2 cm. in depth. This is the only external appearance; there is no sign of hypertrophy or any distortion other than that caused by the pitting.

The presence of the fungus in the cells stimulates the host to lay down a new layer of cork cells surrounding the sorus, if the soil is not too wet, which checks its growth.

By Güssow (1913), who has, as already stated, found powdery scab in Canada, the disease is not considered trifling. He says—

The disease should by no means be regarded lightly. Severe attacks occur when potatoes are planted year after year on infected land. Where this is practiced the result will be potatoes hardly superior in quality to those badly affected with canker. This fact is worthy of notice, especially since, as in the case of canker, no preventive measures have proved of much value.

In a very recent publication, Pethybridge (1913b, p. 459) refers to the damage done by *Spongospora* in his experimental plats, as follows:

They were particularly disastrous on those portions of the land which for special purposes have now been cropped for four successive seasons with potatoes, the cankerous form of the disease being extremely common. In one or two plats nearly two-thirds of the total crop were practically ruined by it, while the general average loss in the plats on the old land due to it would be about one-third of the crop.

EFFECT ON SEED POTATOES.

Besides injuring the potato for market purposes and decreasing the yield, as already noted, powdery scab also depreciates the value

of the potato for seed purposes. Its harmful effect on the seed has been emphasized by Johnson (1908, p. 453), as follows:

Such tubers are not only much reduced in market value for eating purposes, but must provide also poor seed for the next year's crop. Yet I was constantly told that this was the kind of seed regularly planted from year to year; and that the people used this seed because they had, and could get, no other. * * * I have no doubt myself that this *Spongospora* scab has a good deal to do with the miserable average yield per acre of potatoes in the west of Ireland. * * * It is in some districts of Ireland as injurious to potatoes as finger-and-toe is to turnips.

The following sentence from Pethybridge's report in 1911 (p. 442) shows more strikingly the relation of the disease to the seed potato:

It was found during the past season that the crop resulting from the planting of the "canker" form of disease in clean land gave 67.1 per cent of affected tubers, while the spot form produced only 54.1 per cent.

That other countries are not considering *Spongospora* scab lightly is apparent from a farmers' bulletin, No. 110, of the Transvaal Department of Agriculture, issued by Evans in 1910, warning the grower against the use of infected seed potatoes. Evans says—

Corky scab has caused a considerable amount of damage to the potato crop in Great Britain, Ireland, and Norway. It also occurs in Germany, and is particularly prevalent in the west of Ireland. * * * Diseased tubers should on no account be used for seed purposes, for not only will the resulting crop be scabbed, but the ground will also be infected with the germs of the parasites.

It must also be remembered that not only does powdery scab injure the crop, but the soil becomes contaminated and clean seed planted on this land for several years afterwards becomes infested. Just how long the organism can remain alive in the soil is not known, but that it is resistant and may live for several years is suggested by the structure of the spores and experiments by Pethybridge (1911) showing that the spore balls can pass through an animal without losing their capacity for renewing the disease. Contamination of clean seed may take place, it is claimed, by simply being in contact with diseased potatoes. If such is the case, and there is good reason to believe it possible, clean seed may become infected through the use of old bags and machinery. Indeed, it is even possible for one field to become infested from another by the spore balls being carried by the wind, water, and other agencies.

IS POWDERY SCAB A DANGEROUS MALADY?

In considering whether powdery scab is or is not a dangerous disease it is well to keep in mind that any inciting agent, regardless of its origin or nature, that mars or defaces the tuber depreciates its value and ultimately its productiveness. The degree of danger presented by this intruder is problematical, but all American plant pathologists who have expressed an opinion upon this point are agreed that powdery scab is a disease possessing characteristics that

might make it a serious enemy of the potato in the United States, at least as bad as the common scab caused by *Oospora scabies*, and probably worse.

The effect of the milder form of *Spongospora* upon the tuber resembles that of the common scab in that it disfigures the potato and thereby reduces the market price, even though the food value may not be materially impaired. It differs from *Oospora* scab in that the advanced or cankerous stage ruins the tuber for both table and seed purposes.

In this connection it should be remembered that any kind of scab or other injury that mars or defaces the potato tuber is a more serious handicap in the American markets than in those of some European countries, due to the fact that consumers abroad offer fewer objections to scabby potatoes than consumers in the United States. There is even a belief prevalent abroad that scabbiness is an indication of superior quality. In the United States, when potatoes are put on the market, scabby potatoes must be sorted out, and therefore are of no use except for stock feed or the manufacture of starch. In Maine the price of scabby potatoes in the autumn of 1913 was 50 cents per barrel, while clean stock brought \$1.50 per barrel. In the country as a whole, hundreds of thousands of bushels of potatoes are left in the fields because they are too scabby to market. There are frequent instances in the New York markets, according to potato dealers, where carload consignments are rejected because of the presence of numerous scabby potatoes. When the soil becomes infested with scab its value as potato land materially depreciates. This is especially true in sections where potatoes constitute the chief crop.

The character and relationship of the parasite should also be taken into consideration in judging the danger which powdery scab presents. This is a case of dealing with a slime mold, a relative of the serious disease of cabbage, turnips, and related plants, known as clubroot.

If powdery scab should prove no more troublesome in the United States than it has been up to the present in Europe, it would be rated as a disease of secondary importance as compared with late-blight or with *Fusarium* wilt. But there are reasons for fearing that it may become more prevalent here. It seems to be a fact that common scab is less troublesome in Europe than in America, and the same condition might be the case with powdery scab. It quite often occurs that introduced parasites are more destructive in a new habitat than in their native environment. Likewise, it is not impossible that *Spongospora* may find the American varieties of potatoes more susceptible than the European sorts. There is also no means of predicting the behavior of *Spongospora* under the varied climatic and soil conditions of the several States. The parasite has only recently

been found on the American Continent, and the brief experience with it in eastern Canada gives no hint of what its behavior would be in the southern trucking districts, the central West, or the irrigated sections. The common scab is much worse in many parts of the West than in the East.

Another reason for grave concern in the United States is that the disease exists in that portion of Canada adjoining the State of Maine, which is the chief source of seed potatoes for the Central Atlantic and Southern States. If powdery scab becomes generally distributed in Maine, only the most extraordinary efforts can check its spread to nearly every State in the Union.

MACROSCOPIC DIFFERENCES BETWEEN SPONGOSPORA AND OOSPORA SCAB.

It should be made clear in discussing the similarity of and differences between Spongospora and Oospora scab that the symptoms and ultimate effect on the tuber vary markedly in the case of both diseases, depending upon external influences. In spite of the wide variation of powdery scab, two characteristic stages of the disease may be recognized, namely, the scabby and the cankerous stages, shown in Plates II and III, respectively. It is only the former of these that can be easily confused with the Oospora scab, and therefore the latter stage needs no further consideration in this connection.

As pointed out by Horne, the early stages of Spongospora resemble markedly the beginning stages of the wart disease caused by *Chrysophlyctis endobiotica*, in that wartlike excrescences appear on the tuber. Such symptoms are in no way like those of the early stages of Oospora scab, and this naturally leaves for comparison only the characteristics of the two diseases as found on the mature tuber at harvest time and shortly thereafter.

The scabby stage of Spongospora on the mature tuber, as illustrated in Plate II, usually differs essentially from Oospora scab in three ways:

(1) The sori are more often circular and not usually as great in diameter as those of Oospora scab.

(2) The periphery of each sorus is bordered by the upraised outer epidermal layer of the tuber, so that virtually small cups or pits are formed, as shown in Plate II, *B* and *C*.

(3) These pits are usually deeper than those of common scab and are always filled at maturity with a brownish colored semicompacted dust or sediment, as shown in Plate II, *C*. The sori of Oospora are usually shallow and composed of corky material of a compact and interwoven nature.

It should be remembered that it is extremely difficult, if not impossible, to define the difference between two diseases varying so

markedly under diverse environmental conditions. In fact, many cases have come to the attention of the writer where the macroscopic characteristics mentioned were not in evidence, and yet the typical spore balls were found in the sorus upon making microscopic examination. It should be especially emphasized that the three differential characteristics pointed out may be totally absent after the infected tuber has been harvested and roughly handled through shipment.

In Plate II are illustrated what may be called common cases of *Spongospora* and *Oospora* scab. The upper four potatoes are infected with powdery scab and the lower two with common, or *Oospora*, scab.

FUNCTION OF THE SPORE BALLS AND METHODS OF INFECTION.

The potato crop probably becomes infected by the spore balls present in the soil or on the sets when planted. Just how infection takes place is not known. Infection studies are made difficult because no one has been able to germinate the spore balls in abundance at will. Massee (1908) claims that the content of each spore is liberated as a whole in the form of irregularly globose bodies with a few small projections. These bodies show a slow, sluggish movement for some time and then come to rest. Each amoeboid body is about $3\ \mu$ in diameter and uninucleate. Johnson (1908) saw motile bodies resembling swarm spores in his cultures which he believed were the swarm spores of *Spongospora*, but he states that he never saw them escape from the spore. Instead of being uninucleate, he found them to have from one to eight nuclei, like the swarm spores of *Ceratiomyx*. Both Osborn (1911) and Horne (1911) have attempted to germinate the spore balls without being able to confirm either Massee or Johnson. It may be that their germination is seasonal, like the spores of a goodly number of other fungi, or that some special stimulus in the soil is necessary to cause them to become active. That they function can not be doubted, because clean seed planted in soil infested with *Spongospora* spore balls becomes infected with the disease, as shown by Horne's experiments.

It has also been proposed by Massee (1910) that the plasmodia may become encysted during the winter and resume their activity when the tubers begin to sprout, and Johnson (1909) holds that the plasmodium may migrate from the diseased parent tuber into the stem and stolons of the young plant and ultimately infect the young tubers. As suggested by Horne, neither of these investigators has proved experimentally that the plasmodium ever assumes such a rôle. It can not help but become obvious that more information as to the method of functioning of the spore balls and the method of infesting

the soil under field conditions is much needed in order to understand clearly this disease. Such studies are also necessary before control measures can be intelligently worked out.

SEED TREATMENT.

Powdery scab has received little attention from the standpoint of control measures except in Ireland, and the results obtained are not fully convincing. Johnson (1908) states that soaking infected tubers 18 to 24 hours in 2 per cent Bordeaux mixture, or 1 per cent corrosive sublimate for 1½ hours, or 4 per cent formaldehyde solution for 2 hours, is effective in killing the spore balls. It has already been emphasized that very little is known regarding the germination of the spores.

Pethybridge (1911, p. 443) has also studied to some extent the control of Spongospora. His results are shown in Table I.

TABLE I.—*Yield of diseased potatoes when seed was untreated and following various treatments for powdery scab.*

No. of plat.	Treatment of seed potatoes, if any.	Yield of diseased tubers.
		<i>Per cent.</i>
3	No treatment; seed only slightly affected.....	54.1
4	No treatment; seed badly affected.....	67.1
7	Soaked in formalin solution (1:600) for 3 hours.....	2.6
8	Soaked in copper-sulphate solution (1 per cent) for 3 hours.....	0
9	Soaked in copper-sulphate solution followed by rolling in slaked lime.....	4.4
10	Soaked in and covered with precipitate of Burgundy mixture for 3 hours.....	2.9
11	Surface wetted and rolled in flowers of sulphur.....	1.03

Regarding these experiments, Pethybridge says—

From the table it will be seen that in all cases the treatment of the seed tubers resulted in a most satisfactory checking of the disease. With regard to plats 8, 9, and 10, where copper salts were used, the total yield of tubers was, however, quite considerably reduced. The best yield was given with the formalin treatment, and the next best with sulphur. Of these two, perhaps, the sulphur treatment would be the easier to put in practice.

The results obtained by Johnson and Pethybridge are very interesting, but are of a preliminary nature, requiring further study before they can be recommended for practice.

SOIL TREATMENT.

Soil treatment with fungicides for Spongospora scab, as would naturally be expected, has given experimenters but little encouragement. This matter has been most extensively studied for the past three years in Ireland by Pethybridge (1913b, p. 460), whose most recent results follow.

TABLE II.—*Yield of diseased potatoes when soil was untreated and following various treatments for powdery scab.*

No. of plat.	Treatment of land, if any.	Total yield per square perch.	Yield of diseased tubers.
		<i>Pounds.</i>	<i>Per cent.</i>
5	Extra superphosphate added, 4 hundredweight to statute acre.....	99	30.3
6	Each tuber planted in a handful of wet sawdust.....	74	34
7	Extra sulphate of potash added, 1 hundredweight to statute acre.....	102.5	38
8	No treatment.....	100	51
9	do.....	97	52.5
10	Extra muriate of potash added, 1 hundredweight to statute acre.....	94	52.1
11	Flowers of sulphur applied, 6½ hundredweight to statute acre.....	106	23.6

Pethybridge writes as follows regarding these experiments:

With the exception of the muriate of potash, it will be seen that considerable diminution in the weight of diseased tubers produced has been effected by the methods of treatment used, although the use of sawdust has reduced the total yield. The yields given in the above table are pounds per square perch.

The best results were obtained with sulphur, where not only was the amount of disease reduced to less than one-half of that in the untreated plats, but the total yield was higher than in any other case. This result confirms previous experiments carried out at Clifden, which have always shown that sulphur added to the soil increases the yield of potatoes and diminishes the attack of scab. * * *

Substantial as are the reductions in the amount of scab due to the methods of soil treatment above indicated, they can not be looked upon from the practical standpoint as sufficient, and a suitable, cheap soil disinfectant is still a great desideratum for this, as well as for other purposes.

Liming the soil, as is practiced for clubroot of cabbage, a parasite related to *Spongospora*, has proved an aid to the fungus rather than a check to its development. This makes it clear that it does not behave like clubroot of cabbage, as suggested by Massee. The effect of lime on the development of *Spongospora* has been pointed out by Horne (1911) and Pethybridge (1911).

It is, of course, obvious, as Pethybridge suggests, that there is as yet no method of controlling this disease when it once gets into the soil. In view of this fact, it is plain that potatoes should not be grown for some years on a piece of land that has produced a crop infected with *Spongospora* scab. Just how many years the fungus is able to remain alive in the soil is not known and is a question that merits investigation. The nature of the spore balls suggests that the disease may well be able to live in the soil for several years. It should be said also in this connection that if more was known as to the germination of the spore balls, it might be possible to predict their longevity.

SACKS AND BARRELS AS AGENTS IN SPREADING POWDERY SCAB.

It is well known that secondhand sacks, barrels, and boxes are often used in marketing potatoes.

Seed potatoes shipped from the Northern States to be grown in the South are put up either in sacks or barrels. European potatoes coming to this country are shipped in 168-pound gunny sacks. In some of the Western States similar sacks, but holding only 120 to 150 pounds, are used. These sacks cost from 12 to 16 cents each, depending upon their quality and whether they are new or secondhand. Sacks of good quality can be used many times, and this has come to be common practice. In both New York and Boston there are firms that act as clearing houses for potato sacks, buying secondhand sacks from anyone who may wish to sell them and shipping them to potato dealers either north or south. It may happen, therefore, that sacks that have previously contained diseased tubers coming from Europe or elsewhere will be used for shipping select seed from the North to the South. It is not improbable, and, indeed, very possible, that spores of *Spongospora*, *Spondylocadium*, *Fusarium*, *Phytophthora*, etc., may be communicated to healthy potatoes through secondhand sacks. The same thing may take place through using secondhand barrels, but this is not so often done. There is, however, considerable chance of potato diseases being spread by means of old sacks.

The question arises as to how this spreading of disease can be prevented and, of course, the solution is a simple one—by using only new sacks. But this would increase to some extent the cost of potatoes and bring about the accumulation of large quantities of old sacks. It seems very likely that some means of sterilizing old sacks could be put into practice which would make them fully as harmless as agents in disseminating diseases as new sacks. This could probably best be carried out by firms dealing in sacks. It seems probable that subjecting the sacks to steam sterilization for several hours at a pressure of 15 to 20 pounds would render them free from noxious diseases without increasing their cost to any appreciable extent.

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FARMERS' INSTITUTE AND AGRICULTURAL EXTENSION WORK IN THE UNITED STATES IN 1913.

By JOHN HAMILTON, *Farmers' Institute Specialist.*

Reports on farmers' institute work for the year ended June 30, 1913, were received from all the States except Virginia and Washington, the Territory of Hawaii, and the island of Porto Rico. Institutes were held in all the States and Territories except Louisiana, Nevada, Alaska, and Porto Rico. In Louisiana, although a small appropriation is made to the department of agriculture for institute purposes, yet no institutes were held because of the insufficiency of the funds available. Meetings, however, of institute character were conducted by the agricultural college and experiment station. Detailed data regarding institutes are given in the table at the end of this report (pp. 26-33). The more important facts are summarized below.

PROGRESS OF FARMERS' INSTITUTES IN 1913.

The total number of regular institutes held in 41 States during the year was 7,926, of which 6,747 were general, 1,098 women's, and 81 young people's institutes. The total time devoted to institutes was 10,578 days, an increase of 387 days over that reported for the previous year. There was a total attendance at these institutes of 2,897,391, an increase of 7.6 per cent over that of the previous year. Young people's institutes were held in four States and covered 89 days, with an attendance of 22,100. Women's institutes were held in 12 States covering 1,323 days, with an attendance of 84,039—a marked advance over the previous year.

In addition to the regular institutes, there were various activities classed as special institutes, which included 187 movable schools, held in 13 States, occupying 949 days, with an attendance of 85,637; 25 educational trains in 15 States, covering 24,725 miles, carrying 422 lecturers, making 993 stops for meetings and reaching 501,523 persons; 768 so-called independent institutes in 10 States, attended

NOTE.—This publication is of interest to farmers' institute workers in the United States and Canada.

by 197,848 persons; 66 "round-up" institutes in 16 States, with an attendance of 122,400 persons; and 346 farmers' picnics, fairs, conventions, etc., visited and addressed by farmers' institute lecturers, with an attendance of 95,209 persons. Of the movable schools, 50 were for women and covered 362 days, with an attendance of 11,502; 14 were for young people, covering 70 days and having an attendance of 1,344.

The total reported attendance at regular and special farmers' institutes in 41 States was 3,900,008 as compared with an attendance of 4,029,546 in 45 States reported the previous year. There was a falling off in the attendance upon special institutes in 1913 of 447,730, due to the fact that fewer educational trains were run than during the previous year. The average attendance per train, however, was larger than in 1912. In a number of States the educational train seems to have served its purpose as an advertising agency and is being replaced by the more localized and systematic forms of itinerant work.

The total fund reported as available for farmers' institutes, \$510,784, was somewhat less in 1913 than during the previous year. The amount reported as expended for institute purposes was \$474,384, or an average of about \$23 per institute session as compared with \$25 the previous year.

During the year 33 agricultural colleges and experiment stations furnished 415 lecturers at farmers' institutes, and 28 of these institutions report 2,950 days of time given to institute work by their representatives. This shows a falling off of 59 lecturers in the number furnished by the colleges and a reduction of 5.7 days of time for each lecturer during 1913 as compared with the previous year. This is no doubt due to the rapid expansion of the extension feature in the colleges which is now taking the time of college instructors and diverting their efforts from the institutes to the other forms of extension work. This withdrawal, however, does not seem to have diminished the total number of lecturers on the institute force in the several States, the reports showing 1,036 persons listed in 1913 as regularly employed by the State directors as lecturers.

Institute directors in 13 States report that 63 of their instructors gave 385 days of time to teachers' institutes, meeting at these institutes a total of 36,819 persons. Eighty-one persons gave 347 days of time to high-school instruction, meeting 43,191 persons. Twenty-five men gave 41 days to instruction in the normal schools, meeting 16,258 persons. Forty men devoted an aggregate of 387 days to lecturing in the rural public schools, meeting 64,420 children. One hundred and twenty-five men gave 18,439 days to itinerant work among the farmers, giving advice and conducting demonstrations, and 97 men gave 1,824 days to other forms of extension work.

GROWTH OF THE INSTITUTES DURING THE LAST DECADE.

The growth of the farmers' institute movement in the United States during the last 10 years is noteworthy. In the season of 1902-3 there were held 9,570 sessions of institutes in 41 States. In 1912-13 there were held 20,640 sessions, an increase of 115 per cent. The attendance in 1902-3 was 904,654; in 1912-13 it was 2,897,391 at the regular institutes, and at the special institutes 1,002,617; an increase at the regular institutes of 220 per cent and in all forms of institutes 331 per cent. The average attendance at each session increased 49 per cent, or from 94.53 to 141. The appropriations increased from \$187,226 to \$510,784, or 172 per cent. During this period there have developed also the extension departments of the agricultural colleges, which last year reached directly about three millions of people with agricultural information.

The following table shows details of the progress of farmers' institute work from 1903 to 1913:

Progress of the farmers' institute work from 1903 to 1913.

Year.	Regular institutes.					Special institutes, attendance.	Aggregate for all forms of institutes.
	Number of half-day sessions.	Number of States and Territories reporting.	Attendance.	Average attendance per session.	Appropriation.		
1903.....	9,570	41	904,654	94.53	\$187,226		
1904.....	10,622	44	841,698	76.41	212,611		
1905.....	10,555	46	995,192	94.28	225,738		
1906.....	11,409	46	1,299,172	114.00	269,671	326,250	1,625,422
1907.....	11,514	45	1,596,877	138.80	284,450	149,449	1,746,326
1908.....	14,934	44	2,098,268	140.00	325,569	340,414	2,438,682
1909.....	15,535	47	2,240,925	144.00	345,666	617,954	2,858,879
1910.....	16,586	46	2,395,508	144.00	432,374	537,336	2,932,844
1911.....	16,741	45	2,291,857	138.00	432,693	1,323,693	3,615,550
1912.....	19,430	45	2,549,199	131.00	533,972	1,480,347	4,029,546
1913.....	20,640	41	2,897,391	141.00	510,784	1,002,617	3,900,008

This table indicates a steady advance in all directions during the period named. The farmers' institute has shown this steady growth year by year, notwithstanding the rise of many other agencies for rural betterment that have appeared in the last decade. The inherent quality that has enabled the institute not only to hold the interest but to increase the number of its constituency until now it reaches annually about four millions of rural people in the United States is that it meets a need of rural men and women that no other agency has yet been able to supply, viz, a public forum where the scientist and the common man can meet on equal footing and discuss their problems face to face.

It should be noted also that this entire movement has been initiated and conducted without national appropriation for its support and with a minimum amount of departmental aid, thus exhibiting an

initiative vitality and capacity for service to the great body of farmers that no other institution for agricultural improvement in this country can boast.

ADMINISTRATIVE METHODS.

During the past year a request was sent out to the State farmers' institute directors for complete sets of their forms in use in conducting their work—for copies of their instructions to their lecturers and local representatives, advertising posters, postal-card notices, etc., as well as forms of reports by the local managers and institute lecturers on the progress of the work.

There was a very general response to the request. As was to be expected, the methods in use in conducting the work varied in the several States. Where the States were small and all localities easily reached the methods were extremely simple. Where, on the other hand, the States were large and the work correspondingly extended the administrative methods were more elaborate.

An examination of these reports would seem to show that the following facts underlying all institute work should be recognized in planning for conducting it:

(1) That all local people should be fully informed as to the places, dates, and character of the institutes to be held in their community, and that this information should be given widely enough and far enough in advance to enable proper preparations to be made for holding the meeting successfully.

(2) That it is due those furnishing the funds for institute support, whether derived from private or public sources, that the general public, in whose interest the money is given, should have opportunity to enjoy the advantages of the institute. In order to do this, the institute must be thoroughly and effectively advertised.

(3) That this advertising can not be left to chance, but must be systematically undertaken and be prosecuted by individuals directly interested if the meetings are to be a success from the point of view of attendance.

(4) That in order that the State institute director may be informed as to the progress of the work, reports upon the following items are necessary: On attendance, interest manifested, officers selected, expense of conducting the work, plans for the ensuing year, the capability and acceptability of the lecturers, the capability of the presiding officer, the names of influential local people in attendance, subjects discussed, results obtained, amounts contributed by local people, as well as amounts received from other sources.

(5) Detailed information is also needed respecting instruction trains run, movable schools held, round-up institutes, independent institutes, schools aided, local assistance rendered, demonstrations conducted, special institutes, etc.

(6) That the information needed at headquarters for a proper understanding of the institute work is the same as if the director had been present in person at each meeting to observe for himself, or information the same as is needed by the head of a department store or other great enterprise in order to direct it intelligently and to secure its efficiency and success.

(7) Whatever letters of instruction, reports, and advertising methods, therefore, are necessary for securing this information satisfactorily and fully should be adopted and used if the director is to supervise his institute operations intelligently or is to be able to render proper account of his administration of his office and of the funds intrusted to his disposal for institute support.

(8) The reports showed that several States have worked out systems of administration and reporting that are quite complete and in many respects are worthy of imitation. Indiana, Michigan, Pennsylvania, Kansas, Nebraska, New York, and Ohio are among the number.

That there is great need of a careful study of administrative methods, with a view to securing greater efficiency and economy in the use of funds available for institute purposes, is indicated by figures giving the cost of institutes in the United States as a whole and in the different States, as shown in the following table:

Number of days and cost of institutes held in the United States in 1912.

State.	Days of institutes in 1912 and their cost.			State.	Days of institutes in 1912 and their cost.		
	Days.	Total cost.	Average cost per day.		Days.	Total cost.	Average cost per day.
Alabama.....	33	\$1,600.00	\$48.48	Nebraska.....	332	\$18,300.00	\$55.12
Arizona.....	65	1,650.00	25.38	New Hampshire.....	19	1,600.00	84.21
Arkansas.....	213	4,000.00	18.77	New Jersey.....	51	2,500.00	49.02
California.....	129	15,000.00	116.28	New York.....	437	27,009.00	61.80
Colorado.....	150	5,159.00	34.39	North Carolina.....	491	9,530.00	19.40
Connecticut.....	23	819.15	35.61	North Dakota.....	61	11,000.00	180.32
Delaware.....	23	950.00	41.30	Ohio.....	682	27,400.00	40.16
Florida.....	37	8,000.00	216.21	Oklahoma.....	614	10,500.00	17.10
Georgia.....	103	7,500.00	72.81	Oregon.....	77	6,100.00	79.22
Idaho.....	48	4,900.00	102.08	Pennsylvania.....	429	25,500.00	59.44
Illinois.....	421	35,950.00	85.39	Rhode Island.....	28	485.21	17.33
Indiana.....	532	18,750.00	35.24	South Carolina.....	191	3,400.00	17.80
Iowa.....	240	37,245.22	155.19	South Dakota.....	302	13,000.00	43.04
Kansas.....	451	18,000.00	39.91	Tennessee.....	93	5,000.00	53.76
Kentucky.....	119	14,200.00	119.32	Texas.....	744	17,500.00	23.52
Maine.....	119	3,000.00	25.21	Utah.....	297	11,000.00	37.03
Maryland.....	63	6,000.00	95.23	Vermont.....	38	3,000.00	78.94
Massachusetts.....	138	2,751.28	19.94	Washington.....	104	10,000.00	96.15
Michigan.....	590	9,000.00	15.25	West Virginia.....	204	8,203.20	40.21
Minnesota.....	327	25,991.22	79.48	Wisconsin.....	353	19,688.89	55.77
Mississippi.....	258	17,900.00	69.38				
Missouri.....	314	8,750.00	27.86				
Montana.....	146	10,000.00	68.49	Total.....	10,089	487,832.17	48.35

This table indicates in brief that the cost per institute day varied widely, the average for the United States as a whole being \$48.35. While it is true that the expenditures credited to some of the States

in this table were not wholly for institutes proper, a considerable amount going for instruction trains and similar activities, this apparently does not fully explain the great diversity shown. If the Michigan rate of \$15.25 had prevailed throughout the country the number of institute days could have been 31,989 instead of 10,089.

A much lower rate than that of Michigan is reported for the women's institutes of Ontario, namely, \$3.16 per meeting, of which only \$2.40 was supplied by the provincial government, the rest being raised locally. The low cost of these institutes seems to be due in large measure to efficient organization and local initiative. District organizations coextensive with the electoral districts are supplemented by branch societies, each consisting of small local women's clubs throughout the district holding monthly meetings. The members pay annual dues, and other funds for club purposes and for local public improvements are raised in various ways. The strength of the organization is in the fact that the members live in the community, meet frequently, and are active throughout the year. They are not dependent on outsiders who come and go, as are the institutes in most of the States, but they are largely self-sustaining and self-reliant. The fact that 85 per cent of the women's institutes held in Ontario in 1912 were conducted with comparatively little outside aid is proof of the fact that independence, the result of self-support, is possible in the farmers' institute work if proper organization is had for the promotion of this spirit.

The need for multiplying the number of institutes in the United States is such at present that most careful attention to the whole matter of proper organization to supply this need is a paramount duty on the part of those who have control of the institutes in the several States, and the example of Canada in the conduct of its women's institutes and of Michigan in the conduct of its general institute operations are worthy of careful study. The county institute with local branches in every community meeting monthly is the ideal organization both for economy and efficiency for which the institute directors should strive.

The farmers' institute can no longer content itself with the simple discussion of agricultural topics. It is not sufficient that it be merely a debating society or agricultural lyceum. Moreover, it can no longer be an occasional visitor. It must live in the community. If it is to develop local forces, and that is its mission, it must be in daily and hourly contact with those forces. It must take up its abode with those whom it is to benefit, and teach, demonstrate, and guide in the things that it recommends. This means that permanent organizations must be formed in every community.

The institute must identify itself with local people and get to work at once in the community if it is to survive as an educational force.

The statement made before the Country Life Commission of Wisconsin in 1911 by Mr. E. L. Morgan is unquestionably true that "after all the only forces that can deal constructively with rural life are the local forces developed." When this comes to be generally realized and appreciated by extension directors as a fundamental truth, efforts will be made to organize and foster societies for rural betterment in every community in every State.

ASSOCIATION OF FARMERS' INSTITUTE WORKERS.

The eighteenth annual meeting of the American Association of Farmers' Institute Workers was held at Washington, D. C., November 10-12, 1913. Representatives were present from 32 States, 3 of the Provinces of Canada, the District of Columbia, and the islands of Porto Rico and Hawaii.

Reports upon the progress of the work were received from 39 States and Provinces. These showed increased attendance during the year and general interest in the work. Reports from the various standing committees were presented upon the following topics: Institute organization and methods, institute lecturers, cooperation with other educational agencies, movable schools of agriculture, young people's institutes, and women's institutes. Each year the reports of the standing committees become more helpful in solving the difficulties that institute directors and lecturers encounter in the prosecution of their work. This year the committee on organization and methods called attention specially to the extreme importance of having in each unit or district a strong local organization. This was regarded as essential if the institute movement was to become most highly beneficial to the great body of agricultural people.

The value of demonstration as a method of conveying information was also emphasized.

In an extended investigation by the committee on institute lecturers it was found that the average number of lecturers present at each institute throughout the country was 3. Fifteen States reported laboratory exercises in stock judging and household art. Movable schools averaged 5 days in duration with from 4 to 12 teachers for each, the average number of teachers being 5.7. From 20 to 25 per cent of the lecturers are employed by the year. The average age of greatest usefulness in an institute lecturer is between 40 and 50 years, and it was held by all of those reporting that he should have had farm experience.

The committee on cooperation with other agencies recommended that a local or district agricultural council should be organized to direct extension activities in each district, so as to coordinate the work and prevent overlapping.

The committee on institutes for women reported general expansion of institutes of this character, until now most of the State directors report some attention being given to home conditions and woman's life and work. Others report "we are just ready to start." Among the suggestions for the improvement of the work are trained neighborhood visitors, the organization of home-makers' clubs, and the making available of literature giving information respecting home improvement.

One of the significant features of women's work is the enlarging of its scope to include the interests of young girls. In some States girls' canning clubs, bread-making clubs, athletic clubs, and literary clubs are being organized, all designed to arouse and hold the interest and activities of young girls in rural life and its pursuits.

The committee on boys' and girls' institutes summed up its report as follows: States holding special junior institutes, 8; those holding special sessions at regular institutes, 12; those having junior auxiliary institutes, 5; those holding special junior short courses, 8; those having junior sessions at summer short courses, 12; those having regular boys' and girls' club organizations, 36; those conducting junior correspondence courses, 8. The committee reported also that junior encampments seem to be growing in popularity. A criticism was made of the practice sometimes followed of enrolling large numbers in these clubs and requiring no service. It was recommended that members of these clubs not regularly reporting at least once in two months should have their names dropped from the roll.

The "program" of the meeting of the association was divided into four distinct groups—a general session, a special session, a women's session, and a round-table discussion. Eighteen papers in all were presented at these several meetings and discussed.

The president, in his address, spoke particularly of the need for enlisting the cooperation in this institute movement of all classes of citizens, the town resident as well as the people of the rural districts, bankers and business men as well as farmers. He asserted that all were affected directly by the condition of agriculture, and all should, therefore, aid in its improvement.

The officers elected for the coming year were: President, Edward Van Alstyne, Albany, N. Y.; vice president, W. J. Black, Winnipeg, Canada; secretary-treasurer, L. R. Taft, East Lansing, Mich.; executive committee, A. L. Martin, Harrisburg, Pa.; T. B. Parker, Raleigh, N. C., and Mrs. F. L. Stevens, Mayaguez, P. R.

EXTENSION WORK BY THE AGRICULTURAL COLLEGES.

Data regarding extension work by the agricultural colleges in all of the States and Territories except Alaska, Arkansas, Colorado, Hawaii, Maryland, Nevada, South Carolina, South Dakota, Vermont,

Virginia, and Washington are summarized in the table at the end of this report (pp. 34-41), and in less detail in the tables below:

Formal teaching as conducted by the extension departments of the agricultural colleges.

Kinds of schools.	Number in instruction force.	States re-reporting.	Days of service.	States re-reporting.	Persons taught.			
					Registered.	States re-reporting.	Unregistered.	States re-reporting.
Movable schools.....	296	25	5,436	26	72,319	22	100,253	11
Correspondence schools.....	75	12	1,889	8	7,649	12	650	2
Rural study clubs.....	26	6	1,227	6	19,669	5	3,540	2
Normal schools.....	23	7	242	7	9,084	5	595	2
High schools.....	97	11	942	8	5,720	4	16,757	5
Total.....			9,736		114,441		121,795	

Informal teaching as conducted by the extension departments of the agricultural colleges.

Methods employed.	Number engaged.	States re-reporting.	Days of service.	States re-reporting.	Places visited.	States re-reporting.	Attendance.	States re-reporting.
Local advisers.....	298	24	4,995	13	1,933	9	7,888	5
Itinerant lecturers.....	426	25	6,154	15	4,012	18	590,570	18
Educational trains.....	175	22	1,193	19	1,244	20	491,519	20
Rural club work.....	113	28	4,570	17	2,057	11	179,133	12
Demonstration:								
In fields.....	157	26	18,442	18	42,724	16	240,734	12
In animal husbandry.....	56	17	2,676	11	498	10	312,676	7
In home economics.....	50	14	1,241	10	575	9	46,486	8
Miscellaneous extension service.....	359	12	2,372	10	1,644	10	1,073,652	9
Total.....			41,643		54,687		2,942,658	

Publications issued by the extension departments of the agricultural colleges.

Character of publication.	Number issued.	States re-reporting.	Pages.	States re-reporting.
Press bulletins.....	413	21	1,079	17
Bulletins and leaflets.....	102,323	25	3,443	26
Courses of study.....	199	9	1,275	7
Outlines and reports.....	19	7	124	6
Total.....	102,954		5,921	

Financial statement of the extension departments of the agricultural colleges reporting.

Source of income.	Amount.	States re-reporting.
State appropriations.....	\$663,316.00	33
Local contributions.....	160,404.57	17
Other sources.....	166,783.63	19
Total (37 States reporting).....	990,504.20	
Cost last year.....	761,113.53	32
Appropriation 1913-14.....	718,835.00	29

There was general expansion of the extension work of the colleges during the past year. The increase in number of persons engaged in this work was 66 and in the amount of time given to the work over 50 per cent, while the increased amount of time devoted by each person to extension work averaged 27.6 per cent. Thirty-one of the colleges employed 182 persons for their whole time, an average of 5.87 persons per institute, while the number employed for part of their time amounted to 217. The amount of money appropriated increased from \$548,352.82 in 1912 to \$990,504.20 in 1913.

The days of service devoted to movable schools increased from 2,386 to 5,436 and the registered attendance from 36,241 to 73,319. The States reporting correspondence schools in 1912 were 7; in 1913, 12. The days of service devoted to this work in 1912 were 656; in 1913, 1,889; and the number of students registered increased from 2,162 to 7,649.

The States reporting rural study clubs in 1912 were 2; in 1913, 6. The registered attendance had increased from 2,060 in 1912 to 19,669. The number of local advisers in 1912 was 82; in 1913 there were 298; itinerant lecturers had increased from 322 to 426; the places visited by those engaged in informal teaching in 1912 was 12,142; and the persons in attendance, 1,800,513; in 1913 the places visited numbered 54,687; the persons reported in attendance, 2,942,652.

The number of publications issued had increased from 1,949 to 102,954.

It is clear that the extension work of the agricultural colleges is developing very rapidly and along a wide range of effort and that the different institutions are endeavoring to introduce forms of service along extension lines that will be specially adapted to the conditions in their several States.

SECTION ON EXTENSION WORK OF THE ASSOCIATION OF AMERICAN AGRICULTURAL COLLEGES AND EXPERIMENT STATIONS.

At meetings of this section at Washington, D. C., November 12 and 13, 1913, the following topics were discussed: (1) Organization in a college for extension; (2) problems confronting the agricultural colleges in their extension work and suggestions for meeting them; (3) things the college should undertake to accomplish through its extension division and how they should be undertaken; (4) cooperation with other agencies in agricultural extension; and (5) organization in a county or community for extension. The papers and the discussion of them are published in full in the proceedings of the association.

Two very important reports were presented by committees appointed at the Atlanta meeting of the association: One, a committee on organization of courses for preparation of extension workers; the

other, a committee on types of organization. The chairman of the first committee presented a set of tables showing the results of the investigations of the committee respecting the kind of preparation desired by the colleges. As to practical farm experience, the great majority were in favor of this experience as an accompaniment of collegiate training. The second table gave an outline of the courses of study at present required for the preparation of extension workers. In this English predominated, followed by natural science, studies in chemistry, physics, zoology, physiology, and bacteriology. By far the greatest attention was given to chemistry in this preparation. The third group related to lines of work offered by the colleges. Of those reporting, 37 offered work in agronomy, 36 in horticulture, 34 in animal husbandry, 30 in soil management, 17 in farm engineering, 32 in farm management, 27 in home economics, 31 in farmers' institutes. In all, 17 subjects were enumerated, the number of colleges presenting them varying from 17 to 37.

A permanent committee on extension organization and policy was appointed, consisting of W. D. Hurd, Amherst, Mass., three years; K. L. Hatch, Madison, Wis., two years; and G. I. Christie, Lafayette, Ind., one year. The following officers of the section were chosen for the ensuing year: President, W. D. Hurd, Massachusetts; secretary, E. G. Peterson, Utah; recording secretary, John Hamilton, Washington, D. C.

ILLUSTRATED LECTURES.

The series of illustrated lectures issued by this office has abundantly proven its right to a place in itinerant instruction in agriculture. During the past year, from November 1, 1912, to October 27, 1913, the 14 illustrated lectures published by the department were out in use 4,962 days, and a large number of applications for their use was refused on account of inability to supply the lantern slides accompanying the lectures.

CORRESPONDENCE SCHOOLS.

During the year two classes in correspondence work were organized and operated in cooperation with the Pennsylvania State College, one for men and the other for women. The class for men consisted of 21 members and that for women of 15. The classes at the outset engaged to meet twice each week and to continue the study according to the plan outlined by this office, the work to be in charge of a local lay reader under the general supervision of the college of agriculture.

The classes were organized by a member of the institute office visiting the college, and with the advice of the extension director locating the school, enlisting members for the courses, and selecting leaders to supervise the work. This department officer remained on

the ground during most of the continuation of the school as an observer to see the character of the work and to note such defects in its operation as might occur.

After witnessing the progress of the classes for three consecutive weeks this officer reports that the experiment up to that time was successful in every respect. The lay leaders were fully able to oversee the work. The members of the classes were thoroughly interested in the reading and practice exercises. The weekly written examination as reviewed by college experts showed that the students comprehended what they had studied, although some had difficulty in expressing their thoughts clearly in writing owing to their lack of training in this direction. The oral examinations, however, were uniformly good and the attendance was prompt and satisfactory.

AID TO AGRICULTURE BY TRANSPORTATION COMPANIES.

During the year data were collected from railroad presidents and industrial agents in the United States regarding the character of the extension work in agriculture pursued by the roads, viz: (1) Information giving, (2) aid in marketing products, (3) soil improvement, (4) demonstration work, (5) organizing agricultural associations, (6) operating agricultural instruction trains, (7) other activities, and (8) results accomplished.

Returns were received from 57 roads. The mileage represented by these roads was 152,492, or 61 per cent of the mileage of the railroads of the United States operated in 1912. Thirty companies have industrial departments giving special attention to the development of agriculture and employ 144 men in this service. One road reports a force of 45 experts in the employ of the company during the entire year, giving attention to the development of agricultural extension and demonstration work.

Twelve railroad companies each conducted one or more demonstration farms. One has demonstration plats on 133 farms and another conducts 16 farms for demonstration purposes and still another cooperates with 400 farmers in demonstration work. One company furnishes land to farmers for use as demonstration plats. One road reports having organized a farm improvement department consisting of a manager, three assistant managers, and 29 field agents. There is a dairy agent with 7 assistants, and a car fitted up as a model farm dairy at their disposal. There is also a live stock agent with three assistants, and four market agents.

Of the 57 companies reporting, 41 give particulars respecting their work in the dissemination of information, 29 with respect to marketing, 26 on soil improvement, 22 on demonstration work, 17 in organizing agricultural associations, 41 in operating agricultural instruction trains, 28 enumerate other extension activities not embraced by the

other queries, and 26 report satisfaction with the results accomplished.

The transportation companies are evidently awake to the importance of increasing production, partly in that it provides subsistence for the rapidly increasing population, but mainly in its effect upon the revenues of these corporations. Whatever motive may be assigned for the interest that they have manifested, the fact is that much has been accomplished by them in promoting a better agriculture and in securing cordial feeling and close cooperation between these companies and the individual farmer.

AGRICULTURAL EXTENSION WORK IN FOREIGN COUNTRIES.

In order that institute directors and lecturers may be kept informed the following notes by the assistant farmers' institute specialist showing the progress of agricultural extension in foreign countries during the past year are presented:

ENGLAND.—In a memorandum recently issued by the Board of Agriculture and Fisheries to local authorities in England and Wales, grants are offered from a newly established fund known as the "development fund" for use in the furtherance of technical instruction in agriculture and horticulture.

The grants are declared to be in aid first: "For the establishment of advisory councils to be set up in each county or group of counties for the purpose of reviewing, governing, coordinating, or initiating schemes for providing higher agricultural education and educational experiments in connection therewith." Second. "For the provision and maintenance of buildings and lands for farm schools and farm institutes at which young agriculturists and others whose daily business is connected with the land may obtain scientific and practical instruction in the technicalities of their art."

At each of these schools and institutes it is intended that a highly efficient staff shall be maintained to give short courses of instruction suited to the requirements of the district, and also to conduct experimental and research work

The classes and courses of instruction which the Board of Agriculture and Fisheries aids are for "persons of 16 years of age or more who have finished their school education and are either pursuing technical studies with a view of becoming agriculturists, or are already engaged in agriculture and desire to improve their knowledge of the subject."

Prof. T. H. Middleton in his introduction to the report states that it is clearly the duty both of the central and local authorities to devise means for applying to practical farming the knowledge provided by workers in research institutions. He states that until the knowledge of the laboratory has been translated into practice in the field the work of agricultural research is incomplete, and that all the knowledge hitherto obtained in research laboratories will be valueless to any particular locality until it has been applied by farmers to the cultivation of their land. He asks, How is this application of scientific discoveries to the commercial questions of the ordinary farm to be accomplished? Can farmers be expected to study scientific treatises? If farmers did study and understand the publications of research stations, could they afford the time and cost involved in the adaptation of the new principles to the particular circumstances of their own farms?

He refers to the fact that the important task hitherto of the local committees charged with agricultural education has been to provide for the instruction of young persons up to the time when they leave school or college, or to supply itinerant teachers capable, as a rule, of instructing novices only. Now they will be expected to make

provision for advising experienced farmers on the means to be adopted in applying scientific discoveries to practice.

He alleges that it is a mistake to suppose that the proper way to introduce the results of scientific research to farmers is to spread information by means of lectures or leaflets; that *information* can be spread by these means, but not as a rule the results of *research as first published* by the research institutions; that few of the discoveries made by research workers are likely to be immediately applicable to the farm practice of a particular district, but must be modified before they can be utilized. When, however, on a particular farm the success of the new method has been established, neighbors will learn by imitation and the improvement may with advantage then be brought to the notice of others by lecturers and leaflets.

For the purpose, therefore, of translating the results of research into successful practice, a highly trained scientific man is required who has special knowledge of some particular branch of science and a sufficient acquaintance with agriculture to command the respect of skillful and enlightened practical farmers. He states further that for the present all that is practicable is to lay the foundation of a system having as its object the bringing into existence of a class of well-qualified specialists who shall devote themselves to the service of agriculture. The first essential is that the specialist to be employed should really be a specialist. The second essential is that the persons who are to be engaged in the work of promoting agriculture should be of the same caliber as those who have advanced arts like medicine and engineering.

Since no class of agricultural specialists corresponding to the medical specialist exists, it will be necessary to train up men for the work and, therefore, to employ at the outset young and inexperienced persons. For the first few years the work must suffer from this lack of experience, but just as well-trained young medical men quickly acquire experience so will these specialists who are being trained to help agriculturists.

To be really useful either to the large farmer or the small holder the teacher must be a specialist, and if he is a scientific man his attainments in some branch of science should be high; if a practical man he must be a more skillful practitioner than the majority of those whom he instructs.

This announcement of the purpose of the grants by the Board of Agriculture and Fisheries for the furtherance of technical instruction in agriculture and horticulture, and of the policy to be pursued in the expenditure of the funds, is of value to those who are in charge of extension work in the United States because of its careful analysis of the methods to be pursued and the qualifications of the individuals who are to disseminate the information.

The declaration that the discoveries by the experiment stations should, first of all, be placed in the hands of learned scientists who have at the same time practical acquaintance with agriculture, for testing before these truths are given over to ordinary lecturers to promulgate for general adoption is worthy of serious attention. The two classes of extension men are differentiated as to their duties in disseminating information. The observance of the distinction made will help to clear away some of the difficulties that at present embarrass institute and extension directors in this country in organizing their extension work.

ALGERIA.—Under the direction of the Algerian Commission of Technical Agricultural Instruction, Industry and Commerce, a reorganization of Algerian agriculture is taking place which includes the establishing of demonstration farms in all the agricultural regions of the colony.

This reorganization is of interest to extension workers in the United States because of its providing a method of teaching advanced agriculture by means of farms attached to the experiment stations for the purpose of exhibiting in a practical way and upon a considerable scale the results of the researches made by the stations. To these demonstration farms farmers are invited to witness what has been accomplished and to receive instruction respecting the methods employed and the cost incurred in securing the results.

The experiment stations and the demonstration farms are to serve for the instruction of the people by example and also for the propagation and dissemination by sale of the best varieties of seeds and tested plants. They are to conduct researches and experiments in plant and animal production, cultivation, fertilizers, and all farm and garden operations. These demonstration farms are by example also to teach economy and show how to check the many sources of waste and avoid unprofitable practices. They are to keep at the front in agricultural progress and set an example not in a theoretical but in a practical manner for the small as well as the large farmer by demonstrating the method of producing the largest net revenue in each case.

Each station and demonstration farm is located so as to represent the average condition of the different soils, climatic and other conditions in the several regions, and at the same time be easy of access to visitors and have at least some irrigation waters, in order to conduct the vegetable garden and nurseries. The current farm practices of each region are followed, and improvements, as a result of experiments in the experiment stations, joined to each demonstration farm, will be made gradually each year in order that no mistakes may be made and bad examples set. The land for these farms is rented for a long term of years with privilege of purchase, and each farm does not exceed 600 acres except in the dry farming region, where it may include 1,200 acres.

The purely experimental portion of the farm is conducted independently of the demonstration portion and is not expected to be self-supporting. *Each demonstration or model farm is self-supporting and all improvements are made out of its income.* The Government, however, contributes the original funds with which first to stock and equip each experiment station and demonstration farm and makes an annual grant for the experimental work which is connected with each model farm and which, of necessity, can not be expected to be self-supporting.

In order that there may be coordination, harmony, and systematic effort a director, whose salary is paid by the Government, has general charge of all the experiment stations and demonstration farms, and each station has a chief, whose salary is paid out of the annual grant to the experiment stations, while each demonstration farm likewise has a subdirector. The commission also employs scientists to conduct the expert scientific work of the stations, and expert teachers have charge of the instructional work at the demonstration farms.

The supreme object of all the experiment stations and demonstration or model farm work is the practical instruction of farmers in better and improved farm practices. The immediate practical instruction of those now *actually engaged in farming* is regarded as *most important* since it reflects at once and directly on the production of the country, and the demonstration by the model farm method is deemed the quickest and surest method of accomplishing this end. Accordingly, farmers' meetings are held at frequent intervals at the model farms, and practical instruction by demonstration is given to those in attendance. No theoretical instruction is attempted, and nothing not fully proven and demonstrated is given. The model farm thus becomes a permanent agricultural exposition and demonstration school where the farmers go to see the things they are to learn, and to discuss them in the fields as they are conducted about the farm. After certain improved practices have become fully and surely demonstrated at the model farm, small fields on many individual farms are used to disseminate still further the information by practical demonstration under the direction of the central farm, but the entire actual work is there done by the farmer himself.

During the lax or dormant season farmers' meetings are held throughout the country in order to interest the farmers in the demonstration farms and to sell improved seeds, plants, and animals from the model farms.

BELGIUM.—Meetings or conferences for the instruction along agricultural lines of adults actually engaged in agriculture have been held for a number of years in various villages in Belgium by the agricultural supervisors, agricultural engineers, professors of agriculture, and others holding diplomas permitting them to give such instruction.

The subjects discussed at these meetings include fertilizers, feeding of domestic animals, hygiene, dairying, cooperative association, rural law, the combating of the enemies of plants and animals, apiculture, poultry, and farriery.

The following lists of meetings of adult farmers with the attendance for the last three years show the progress of the work.

Meetings of adult farmers, with attendance for 3 years, 1908-1911.

Kinds of meetings.	1908-9	1909-10	1910-11
Meetings by the agricultural supervisors:			
Number of conferences.....	1,154	1,157	1,119
Average attendance at each conference.....	50	50	50
Total attendance.....	57,700	57,800	55,900
Meetings during the winter:			
Number of conferences.....	3,170	3,440	3,670
Average attendance at each conference.....	49	53	55
Total attendance.....	155,330	182,320	201,850
Agricultural meetings for the army:			
Number of conferences.....	550	528	572
Average attendance at each conference.....	27	23	26
Total attendance.....	14,850	12,144	14,872
Meetings on apiculture:			
Number of conferences.....	388	330	366
Average attendance at each conference.....	26	26	26
Total attendance.....	10,088	8,580	10,248
Meetings on poultry culture:			
Number of conferences.....	355	336	437
Average attendance at each conference.....	46	44	53
Total attendance.....	16,330	14,784	23,161
Meetings on farriery:			
Number of conferences.....	252	240	252
Average attendance at each conference.....	31	29	28
Total attendance.....	7,812	6,960	7,056
Special meetings:			
Number of conferences.....	655	752	614
Average attendance at each conference.....	50	50	60
Total attendance.....	32,750	37,600	36,840

SWEDEN.—There is probably no country in the world where agricultural education is better organized and more appreciated than in Sweden. The farmers' schools in that country make provision for those actually engaged in agricultural work who can spare only part of the year for improving their education. There are 30 of these farmers' schools in Sweden, and they usually form a special part of the work of the people's high schools which provide for the general education of adults. The work of the farmers' schools is based on and is an extension of the general training given in the people's high schools.

During the year 1909-10 the 30 schools were attended by 476 pupils, of whom 266 paid their own fees. The number of students per school ranged from 4 to 40. The ages of the pupils varied from 16 to 33 years, the average being a little over 20½. The Government grant is from \$825 to \$1,100 per annum for each school, and at least an equal sum must be raised locally.

A summer course in household economy for women was held from May 1 to October 3, 1912. There were 6 special students of the average age of 20½ years working together with a number of ordinary high-school pupils. The practical instruction includes cooking, related business transactions, and baking of various kinds. Each pupil in

turn was responsible for the preparation and serving of a dinner. The theoretical instruction included the nutritive value of different foods, dietetics, food preservation, tests of fitness or unfitness of food for home consumption, domestic economy, cost of meals per head, care of the home, and rules of health. The pupils also received instruction in hygiene, chemistry, physics, bookkeeping, care of farm stock, dairying, sociology, singing, and gymnastics. The tuition fee for the summer course is \$8.75.

The Swedish system of education also provides for instruction in veterinary science, farriery, horticulture, forestry, the peat industry, fisheries, and economics; besides which there are itinerant agricultural schools and specially arranged schools for small holders. Another very interesting kind of educational work is now being developed, namely, instruction in the methods of canning fruits, preparation of dried fruits, jam making, preparation of preserves, etc., by means of traveling vans fitted up with the necessary apparatus.

ITALY.—The expenses of the itinerant chairs of agriculture have been classed heretofore as "optional expenses," and therefore subject to cancellation by the provincial administrative assemblies for the communities when exceeding the limits of overtaxation. The statute of June 12, 1912, modifies this requirement as follows: "The Province and its communities which exceed the limit of overtaxation possess the authority to approve or register the optional expense balances with the same provisions by which excesses are authorized, always when such expenses are evidently necessary for health, instruction, beneficence, agriculture, and the conservation of itinerant chairs of agriculture."

FRANCE.—The law of August 21, 1912, relating to departmental and communal agricultural instruction provides a director of agricultural services in each Department in place of the departmental chairs of agriculture established by the law of June, 1879. The work of this director includes: The popularization of agricultural knowledge; the teaching of agriculture; in the establishment of public instruction selected by ministerial decree; the service of the economic and social interests of agriculture and of agricultural insurance and rural hygiene; agricultural information, statistics, and food supply; the direction of experimental fields; researches or technical missions, and in general, all the services to do with agriculture. The veterinary and forestry services and the direction of agricultural stations are not included in these duties.

The departmental professor of agriculture shall hereafter be entitled "director of the agricultural services." He is assisted by one or several agricultural lecturers, who hold special positions, whose sphere of work is variable and comprehends all or part of one or several "arrondissements." These spheres may be extended still further in the case of specialists. By resolution of the chamber, a credit of \$182,000 was incorporated in the budget for 1912, and of this \$160,000 is to provide salaries for these State functionaries and \$22,000 is for other expenses which the Department or communes have to meet.

The range of duties of the Department professors has remarkably increased. At present their duties may be divided into two groups: They are on one hand a kind of information bureau where farmers may seek advice in all matters, and on the other they serve as agents of the central administration for conducting investigations of the most varied nature. Under this latter head they must make a monthly report upon the general condition of agriculture in their special territory, and further upon tillage areas and growing and ripened crops, and finally conduct special investigations.

The appointment of professors of agriculture has as a prerequisite the passing of a competitive examination under the Ministry of Agriculture, upon which the bill contains some provisions. The candidate must be 25 years of age, be a graduate of the agricultural college (Institute National Agronomique) or of one of the agricultural national schools with two and one-half years' curriculum and an uninterrupted two years' experience in agricultural administration after graduation. The appointment

and adaptation for the position of a professor of agriculture is determined by a jury, of whom three are practical farmers. In case of a vacancy in an agricultural directorship a competitive examination is announced, but the post is filled by a professor of agriculture who has already filled this office at least five years. These provisions do not, of course, apply to functionaries already in office.

The State is responsible for the salaries of both classes. The salary of director of agriculture ranges in four grades, from \$900 to \$1,200. That of professor of agriculture from \$560 to \$800. Advancement to the next higher grade occurs after at least three, at most five, years. Both classes are subordinate to the Minister of Agriculture, who exercises supervision through general inspectors and inspectors in administrative matters through the governors of Departments.

The Department must assume the office and traveling expenses of the director of agriculture and the professor of agriculture assigned to him. The Department or commune must defray the expenses of the other professors of agriculture. At least \$240 annually for the traveling expenses must be included in the Department's budget.

It is hoped by taking this course with regard to the position and salary of directors and professors of agriculture to exert a still more beneficial influence for the advancement of agriculture. As a matter of fact, the union of itinerant instruction with certain public functions and with the instructorship in elementary schools and normal institutions seems to be a measure worthy of imitation.

PRUSSIA.—An editorial in the *Journal of the Board of Agriculture (England)*, April, 1913, number, discusses quite fully the system of agricultural education in Prussia. Attention is called by the writer to the fact that more and more theoretical instruction in agriculture is given in the schools and less of the practical. This is attributed to the tendency of the practical man who becomes a teacher to stereotype his subjects and gradually lose sight of the practical features of the work.

This tendency is to some extent overcome by the practice of withdrawing these teachers from their schools during the summer and starting them out on itinerant work, thus bringing them for a considerable portion of each year in contact with the actual operations of agriculture. It is claimed that this contact with the farmer is not only of great advantage to the teacher and the farmer, but to the scholars in the schools to which the teacher returns in winter. There seems to be no doubt in the mind of the writer that much of the efficiency and popularity of the winter schools are due to the freshening influence and practical experience that the instructor has gained through contact during the itinerant period with farming people.

Peripatetic work in Prussia is carried on by two distinct classes of persons: First, the teaching staffs of the winter schools, who devote only part of their time to peripatetic service, and, second, a class who devote their entire time to this kind of work. The last class is employed for the most part by the Chamber of Agriculture while the necessary funds are supplied by the State. Their activities are not limited to the delivery of lectures, but they are required also to see that new ideas and inventions are brought to the attention of agricultural people in their respective districts. The effort on the part of the chambers of agriculture is to employ for this continuous service men who, in addition to possessing all-round knowledge of agriculture, have also special knowledge of some particular branch of the subject.

In addition to the more informal methods practiced in giving instruction a large number of special courses on various subjects are conducted for the benefit of agriculturists in all parts of Prussia. The majority of these are short, practical series of lectures on subjects such as bookkeeping, manures, pig breeding, etc. There are also courses of instruction for country women and girls in domestic economy and similar subjects. There is also a large amount of continuation school work carried on, also a system of colleges for training agricultural teachers to supply the necessary pedagogic skill to peripatetic teachers who possess theoretical and practical knowledge but have no teaching experience.

A very important fact is noted by the writer to the effect that there is a tendency on the part of the winter schools to increase in number and of the lower agricultural schools to decrease. This is attributed to the fact that the agricultural population, from whom the students are mainly drawn, appreciate the theoretical education given in winter, but do not appreciate the practical instruction given during the rest of the year, when equally good and at the same time paid practical experience can be obtained on farms.

STATE REPORTS.

Detailed information respecting institute work in the several States is given in the statistical tables accompanying this report. Numerous items of interest, showing the progress of the work, but which are incapable of tabulation, appear in the reports of the directors. In order that these features may be known by the body of workers, the principal points presented are referred to in the following accounts under the names of the respective States:

ALABAMA.—A round-up meeting and summer school for institute workers was held at the Alabama Polytechnic Institute, continuing through 84 sessions, with a registered attendance of 900.

ALASKA.—The farmers in Alaska are so widely scattered and travel so costly that it is impracticable to organize or maintain farmers' institutes. There are, however, approximately 2,000 people in the Territory who have small gardens. In the towns and in some camps are market gardeners who make a success of the business. There are vast areas of wilderness that could be made into farms, but the director reports that settlement can not and will not be made until railways are built. The principal need at present is money to pay the salaries and expenses of traveling instructors.

ARIZONA.—The special topics assigned to be discussed in every institute during the season were dairying, dry farming, good roads, and insect pests. The new features introduced into the institute work were the demonstration train, the farmers' fortnightly course at the university, and the farmers' institute at county fairs. The great need for the development of the work is more money to increase the number of institute workers.

ARKANSAS.—A school for boys and girls was held at the State fair and on May 31 there was held what was called "Silo Day" at the agricultural college. Changes in the faculty of the college and the staff of the experiment station, together with meager appropriation for institute purposes, has seriously interfered with the development of the work.

CALIFORNIA.—The new features introduced into the institute work during the year were the formation of women's agricultural clubs, and the appointment of itinerant and county advisors. Owing to differences in local climates and leisure seasons in various parts of the State, institutes are held every month. The State legislature has increased the farmers' institute appropriation per annum from \$15,000 to \$25,000.

COLORADO.—Many counties in Colorado have no agricultural interest, consequently institutes are held in a limited number only. The work is so closely combined with that of college extension that no well-defined line of separation exists, making it difficult to report separately upon these two features of extension. The failure of the State to pay the appropriation this year has prevented much that had been planned.

CONNECTICUT.—The farmers' institute work formerly carried on by the State board of agriculture, the Connecticut Dairymen's Association, and the Connecticut Pomological Society has been combined under a single directive head. An effort is being made to bring the institutes into closer relations with the agricultural fairs. Several

meetings at these exhibits have been held and arrangements are being made for the formation of a State association.

DELAWARE.—The special topics assigned to be discussed in every institute during the past season in Delaware were poultry and home economics. An educational train was run during the first week of December over the Chesapeake and Delaware Peninsula, making 15 stops in Delaware and 15 in Maryland. The total attendance was 2,684. The topics discussed by the lecturers accompanying the train were tomato culture, fruit culture, live stock, corn growing, poultry, and alfalfa.

FLORIDA.—The new features introduced into the institute work in Florida during the year were county institutes and produce contests. There was a live-stock convention and a citrus seminar was held. Lectures were also given at agricultural fairs. The director, in answer to inquiry as to the particular assistance needed in his work, replied "more publications."

GEORGIA.—In Georgia the principal new feature introduced into the institute work during the year was the development of the county institute by organizing them with a full set of officers and the adoption of a constitution and by-laws. During the year a live-stock conference and breeders' meeting, and several horticultural meetings were held and a number of agricultural excursions made to the college and experiment station.

IDAHO.—The State has increased the appropriation for institute work from \$4,000 a year to \$12,500. The number of movable schools has been increased, county agents have been appointed, and summer picnic institutes held in regions not easily accessible in winter. It is proposed to lessen the number of old-time farmers' institutes as the movable schools and county agents increase in number. There has been added to the staff in the field a home economics extension worker and horticultural expert. The subject of live stock was assigned to be discussed at every institute held in the State. A new feature was introduced into the work in the form of a round table exercise. The first session at each institute included this round table discussion.

ILLINOIS.—In Illinois the county institutes are independent organizations established by law and are assisted by the State with funds and speakers when these are applied for. The agricultural college and experiment station workers serve only when called upon. An annual convention of the farmers' institute workers is held each year, continuing for a week, at which the election of district directors is held. Provision is also made for women's auxiliaries and special features are provided by the institute for the instruction of young people along agricultural lines.

INDIANA.—An annual conference was held in October consisting of six sessions; the average attendance of the active workers was 31, and the average attendance of workers and visitors together was 55. Greater emphasis is being placed upon the organization of boys' and girls' school clubs.

IOWA.—In Iowa the county institute is an independent organization. The money is appropriated to the amount of \$75 directly to each county holding an institute of not less than two days during the year. An annual convention is provided for, at which each institute organization is entitled to representation provided it has been organized at least one year and has reported to the State secretary of agriculture through its president and secretary or executive committee that an institute was held according to law. In connection with the annual convention, either preceding or following the date on which officers are elected, the State board may hold a State farmers' institute for the discussion of practical and scientific problems relating to various branches of agriculture.

KANSAS.—The new features introduced into the institute work in Kansas during the past year were boys' institutes and demonstration work by county and district agents. The subjects taught on the railroad instruction trains were diversified farming and home management. Institutes, also were held in connection with orchard demonstrations. There were also dairy institutes and other meetings for special purposes not on the regular institute schedule.

KENTUCKY.—Corn clubs, corn judging shows, home coming rallies, and orchard demonstration meetings were held under the auspices of the farmers' institute. Among the new features was the organization of women's home economic clubs as auxiliaries to the farmers' institutes.

LOUISIANA.—The farmers' institute work in Louisiana is by law placed under the direction of the commissioner of agriculture and immigration. Owing to the meager appropriation no institutes have been held by this department, but meetings of similar character have been conducted by the director of the State experiment station at Baton Rouge.

MAINE.—The law in Maine requires that two institutes shall be held in each county each year. Considerable attention has been given during the past year to assisting at meetings held in the interest of cooperation among farmers and in assisting in organizing associations of this character. In addition to the regular institutes lecturers have been sent to 37 meetings of granges.

MARYLAND.—A new feature introduced into the farmers' institutes during the year was the illustrated lecture. This has been found to be a very effective method of impressing agricultural truth. The illustrations are taken from Maryland farms and from work done at the agricultural experiment station and the college.

MASSACHUSETTS.—This year the Massachusetts Board of Agriculture voted to amend the rule relating to institutes so as to require societies to hold at least one institute each year instead of three as in the past. The plan is to spend more money on the one meeting, have more and better speakers, and to advertise each meeting more thoroughly. The secretary of the board is to assume immediate control and give greater assistance without taking the actual arrangements out of the hands of local committees. A summer field meeting of the board was held continuing through one day, and also a public winter meeting continuing for three days.

MICHIGAN.—The new feature introduced into the institute work during the year was cooperation with county agricultural advisors. Calls for new work also came in the form of more meetings of the women's congresses. This was insistent and the institutes are beginning work in this direction by holding from two to six meetings a year, the latter number where the organization is firmly established. The plan is to place in the hands of each of the congresses an outline to be followed much as study clubs are carried on, these to be supplemented by suggestions, questions, and helps from the department, and with the traveling libraries and loan collections of pictures from the State libraries, which are furnished without charge to such organizations. The topics considered at these meetings will be practical ones which affect the home and household, such as sanitation, cookery, scientific cleaning, canning fruits and vegetables, home nursing, home gardens, and such topics as the schools, preservation of trees, birds, public buildings, and grounds, and good roads. The department sends also an outside lecturer or demonstrator to at least two of these meetings during the year. It is planned to exchange speakers by sending members of the local congresses from one county to the next, thus working cooperatively. The topics treated by lecturers accompanying the institute trains were alfalfa, dairying, beekeeping, and agronomy.

MINNESOTA.—In Minnesota the new feature was that of granting assistance to county agent work. The institute board aided nine counties in this direction, using in all \$1,675 for this work.

MISSISSIPPI.—The new feature introduced into institutes in Mississippi was the organization of farm clubs for production and market demonstration. The clubs are organized for growing sweet and Irish potatoes, corn, cane, and hogs, and for the cooperative and systematic marketing of these products. This work is being done chiefly in the section devastated by the Mexican boll weevil. It is the purpose to establish county organizations and extend the work to every district in the State. The institute work in the summer begins July 1, running three months. The winter period begins December 1, continuing for a like period. The interim between each active season

is spent by the department officers in correspondence, organization, planning of work, lecturing before schools, institutes, and normals. The topics discussed from institute trains were live stock, soils, and general crops.

MONTANA.—The new feature introduced during the year was the inauguration of a farmers' week and calling a country life convention at the agricultural college. There were also demonstrations held at the experiment station farms under the auspices of the institute division.

NEBRASKA.—The new feature introduced by the Nebraska institutes was fruit-tree pruning demonstrations. The institute authorities are also urging the one-week short course and expect to hold a considerable number of these next year. Special fruit institutes were held, and assistants was also given at farmers' club meetings.

NEW HAMPSHIRE.—A summer field meeting was held continuing through two sessions with an attendance estimated at 2,000. A new feature introduced was demonstrations at the institutes by the use of live stock on the platform. A new law was enacted by the legislature in 1913 by which a department of agriculture was created and the State divided into three agricultural districts. In addition to the commissioner of agriculture, the governor was authorized to appoint six practical agriculturists, two of whom shall reside in each of the districts, constituting an advisory board of the department of agriculture. They are allowed their actual and necessary expenses while performing official duty and the additional sum of \$4 per day. They are required to meet at the office of the commissioner of agriculture as often as once in two months to advise with him as to the work of the department. The commissioner is required to hold one or more farmers' institute meetings in each county annually and at least one State meeting. He is required to cooperate so far as may be practicable with the extension work of the college of agriculture and mechanic arts, and is required to provide courses of study of one week or more to be pursued in connection with the county demonstration meetings in counties offering satisfactory agricultural cooperation. He is also required to cooperate with the State superintendent of public instruction in the preparation of elementary courses in agriculture for secondary schools, as well as courses for elementary work in the lower grades of the common schools.

NEW JERSEY.—In addition to the regular institutes held throughout the State, lecturers were provided for meetings for Jewish people, for Y. M. C. A. conventions, corn growing associations, country church clubs, county schools of agriculture, and agricultural clubs.

NEW MEXICO.—The work in New Mexico consisted almost entirely of running agricultural trains. During June, July, and August 17 of the county teachers' institutes were attended by the superintendent of agricultural extension and his assistant. Boys' and agricultural industrial club work was conducted, but chiefly through correspondence. The lack of an appropriation for institute work has limited the efforts of the director to the work designated.

NEW YORK.—In one county in New York a series of lectures was given in lieu of the institutes. The farmers' institute bureau is cooperating with the county bureaus now organized in 17 counties of the State. The work of forming and supervising cow testing associations has been added to the duties of the farmers' institute. Twenty-five such associations are now in operation. Summaries of the addresses of institute lecturers were printed and distributed, thus permitting persons present at their delivery to take home for future reference the facts presented. The director of farmers' institutes holds conferences annually in all of the counties. At these conferences he meets representative farmers, at which time the institutes and other agricultural work for the year are arranged for. A local correspondent is selected for each institute, his duties being to arrange for securing a suitable hall and to assist in advertising the meeting. Special topics, lime and humus, were assigned to be discussed at all institutes, and in the dairy section the organization of cow testing associations. Approximately 450 farms were visited and spraying and other demonstrations given.

NORTH CAROLINA.—A new feature of the work in North Carolina was the holding of a three-day normal or training institute for the benefit of lecturers prior to their starting out on institute work. This year before making up the programs or selecting the speakers the director wrote to members of the committees in the several communities asking them to suggest topics that would in their opinion be likely to be most helpful to their different localities. Two hundred and thirty-two days of women's institutes were held, consisting of 460 sessions and attended by 20,268 women. The dates, places, and programs of the institutes are arranged by the State director in consultation with the local committees. Thirty-five thousand reports of the proceedings of the institutes were printed and distributed.

OHIO.—Under the new law the number of institutes required to be held in each county has been increased from four to five. The funds are distributed on the basis of \$300 for each of the 88 counties. The dates, places, and programs of the institutes are arranged by the institute committee of the State board of agriculture.

OKLAHOMA.—Owing to radical changes in the law, institutes have been without organization since January, 1913. This was brought about through a bill which recalled the board of agriculture and practically destroyed the institute organization. Institutes for women, however, were held as usual, to the number of 497, attended by 30,922 women. The entire appropriation for women's work was \$5,000. The special feature introduced during the year was that of home nursing and rural hygiene.

OREGON.—In Oregon an act was passed appropriating \$25,000 per annum to conduct and encourage educational extension demonstrations and field work in the several counties of the State to include agriculture, horticulture, dairying, domestic science, and other industries. The several counties were also authorized to provide and appropriate funds for use in agricultural or farm demonstrations and field work, and for each dollar so provided by the county there should be the sum of \$1 in addition to the appropriation of \$25,000 to be paid out of any moneys in the State treasury not otherwise appropriated. The total amount so appropriated to any county having an area of 5,000 square miles or less, not to exceed \$2,000 in any one year; and to any large county not to exceed \$4,000 in any one year. A woman has been employed for the domestic science and art work, one man has been employed for extension work in horticulture, and another is to be added for the work in animal husbandry and dairy production.

PENNSYLVANIA.—The last Legislature of Pennsylvania enacted a law providing for the employment by the institute director of 10 farm advisors whose duties shall be to visit the farmers of the State and aid them in all questions relating to farm operations, embracing crop rotation, drainage and water supply, small fruits, market gardening, horticulture, animal husbandry, dairying, and poultry. An appropriation of \$40,000 for the season was made for carrying this act into effect. The legislature also increased the regular appropriation for farmers' institute work from \$22,500 to \$27,500. The following special topics were assigned to be discussed in every institute during the year: Poultry, dairying, horticulture, soils, and market gardening. An appropriation of \$12.50 per day is allowed to each county chairman for hall rent, printing, and hotel and traveling expenses. The balance of the appropriation by the State is used by the State director in paying for the services, hotel and traveling expenses of lecturers.

RHODE ISLAND.—No special appropriation was made for farmers' institute work, but the sum of \$700 was set aside for this purpose from the fund appropriated for the general work of the board of agriculture. Demonstrations for controlling tree pests, also in pruning and spraying were held under institute auspices. The institute lecturers also devoted a considerable amount of time to the development of school garden work and in conducting industrial contests.

SOUTH CAROLINA.—A new feature of the institute work in South Carolina has been the holding of institutes on the farms, using the stock and field crops for illustrative

material. All of the work of instruction is by members of the faculty of the agricultural college and by demonstration agents in the various counties.

SOUTH DAKOTA.—The Legislature of South Dakota increased the appropriation for farmers' institute purposes from \$16,000 to \$20,000 per annum. A ladies' auxiliary of the farmers' institutes has been organized and a lady has been placed in charge of this department. Meetings for women were held at 128 points, with a total attendance of 11,826. The special topics discussed during the year in the men's institutes were alfalfa and corn growing.

TENNESSEE.—Institute work during the last year was confined almost wholly to agricultural trains. Owing to legislative entanglements no appropriation for farmers' institutes was made. Notwithstanding the lack of funds, however, three round-up or divisional institutes were held by the commissioner of agriculture, who is in charge of the institute work in this State.

TEXAS.—In cooperation with the State entomologist the farmers' institute director has appointed in each district a local entomological observer to report on insect pests. He has also organized a large number of baby beef and boys' and girls' hog clubs. Special meetings were held by the pathologist and entomologist for demonstrations in spraying against codling moth and other insect and fungus diseases. Five institute trains were run. The topics presented were soil mulching, seed selection, stock and poultry rearing, silo construction, and control of insect and fungus diseases.

UTAH.—The special topics discussed at the institutes in Utah during the past season were conservation of irrigation water; economy in time, energy, and labor of men and women. Among the new features introduced were the appointment of county chairmen, and the publication of synopses of addresses to be distributed among the audiences. An institute train was run, the subjects taught being animal husbandry, dry farming, and irrigation.

WEST VIRGINIA.—At the last session of the legislature a law was enacted transferring the farmers' institute work from the board of agriculture to the control of the college of agriculture at Morgantown. Under the direction of the university, four institute trains were run, with a total attendance of 16,490. The subjects taught were soil improvement, poultry, and market gardening. Lecturers from the institute force were present at teachers' institutes, high schools, and normal schools. Six itinerant experts were employed in field demonstration work and as agricultural advisors to individual farmers. These each devoted 11 months to this service.

WISCONSIN.—In Wisconsin the special topics discussed at the institutes were soil conservation, crop rotation, silos, cooperation, dairying, and the growing of alfalfa. A number of new institute lecturers were employed during the year, among whom was a representative of the Wisconsin Live Stock Breeders' Association. In addition to the instruction given by lectures at the institutes, an edition of 10,000 copies of a cookbook was published and distributed.

STATE OFFICIALS IN CHARGE OF FARMERS' INSTITUTES.

ALABAMA.—C. A. Cary, Alabama Polytechnic Institute, Auburn; Reuben F. Kolb, commissioner of agriculture, Montgomery.

ALASKA.—C. C. Georgeson, Agricultural Experiment Station, Sitka.

ARIZONA.—A. M. McOmie, superintendent of farmers' institutes, Tucson.

ARKANSAS.—Martin Nelson, director of farmers' institutes, Fayetteville.

CALIFORNIA.—W. T. Clarke, superintendent of university extension in agriculture, Berkeley.

COLORADO.—C. H. Hinman, director of farmers' institutes and extension, Fort Collins.

CONNECTICUT.—L. H. Healey, secretary State board of agriculture and director of advisory board of farmers' institutes, Hartford.

DELAWARE.—Wesley Webb, corresponding secretary, State board of agriculture, Dover.

FLORIDA.—P. H. Rolfs, director Agricultural Experiment Station, Gainesville.

- GEORGIA.—A. M. Soule, president State college of agriculture, Athens.
- HAWAII.—Wm. Weinrich, jr., secretary and treasurer farmers' institutes, Box 583, Honolulu.
- IDAHO.—W. H. Olin, superintendent of extension, 439 Yates Building, Boise.
- ILLINOIS.—H. A. McKeene, secretary Illinois farmers' institutes, Springfield.
- INDIANA.—W. C. Latta, farmers' institute specialist, Lafayette.
- IOWA.—A. R. Corey, secretary State board of agriculture, Des Moines.
- KANSAS.—Edward C. Johnson, superintendent of farmers' institutes and demonstrations, Manhattan.
- KENTUCKY.—J. W. Newman, commissioner of agriculture, labor, and statistics, Frankfort.
- LOUISIANA.—E. O. Bruner, commissioner of agriculture, Baton Rouge; W. R. Dodson, director Agricultural Experiment Station, Baton Rouge.
- MAINE.—J. A. Roberts, commissioner of agriculture, Augusta.
- MARYLAND.—R. S. Hill, director of farmers' institutes, Upper Marlboro.
- MASSACHUSETTS.—Wilfred Wheeler, secretary State board of agriculture, Boston.
- MICHIGAN.—L. R. Taft, superintendent of farmers' institutes, East Lansing.
- MINNESOTA.—A. D. Wilson, superintendent of farmers' institutes, University Farm, St. Paul.
- MISSISSIPPI.—R. H. Pate, director of farmers' institutes and extension, Agricultural College.
- MISSOURI.—T. C. Wilson, secretary State board of agriculture, Columbia.
- MONTANA.—F. S. Cooley, superintendent of farmers' institutes, Bozeman.
- NEBRASKA.—C. W. Pugsley, superintendent agricultural extension, Lincoln.
- NEVADA.—J. E. Stubbs, president Nevada State University, Reno.
- NEW HAMPSHIRE.—N. J. Bachelder, secretary State board of agriculture, Concord.
- NEW JERSEY.—Alva Agee, director of farmers' institutes and agricultural extension, New Brunswick.
- NEW MEXICO.—W. T. Conway, superintendent agricultural extension, State College.
- NEW YORK.—Edward Van Alstyne, director of bureau of farmers' institutes, Albany.
- NORTH CAROLINA.—T. B. Parker, director of farmers' institutes, Raleigh.
- NORTH DAKOTA.—G. W. Randlett, superintendent of farmers' institutes and extension, Agricultural College.
- OHIO.—A. P. Sandles, president agricultural commission, Columbus.
- OKLAHOMA.—Miss Irma Mathews, superintendent women's institutes, Oklahoma City.
- OREGON.—R. D. Hetzel, director extension department, Corvallis.
- PENNSYLVANIA.—A. L. Martin, deputy secretary of agriculture, Harrisburg.
- PORTO RICO.—F. L. Stevens, in charge farmers' institute work, Mayaguez.
- RHODE ISLAND.—John J. Dunn, secretary State board of agriculture, Providence.
- SOUTH CAROLINA.—W. W. Long, State agent and superintendent of farmers' institutes and extension, Clemson College.
- SOUTH DAKOTA.—H. H. Stoner, superintendent of farmers' institutes, Highmore.
- TENNESSEE.—T. F. Peck, commissioner of agriculture, Nashville.
- TEXAS.—J. W. Neill, director of farmers' institutes, care State board of agriculture, Austin.
- UTAH.—E. G. Peterson, director of agricultural extension, Logan.
- VERMONT.—Elbert S. Brigham, commissioner of agriculture, St. Albans.
- VIRGINIA.—J. J. Owen, director of farmers' institutes, department of agriculture, Richmond.
- WASHINGTON.—J. A. Tormey, head extension department, Pullman.
- WEST VIRGINIA.—C. R. Titlow, director of farmers' institutes and extension, Morgantown.
- WISCONSIN.—George McKerrow, director of farmers' institutes, Madison.
- WYOMING.—H. G. Knight, director Agricultural Experiment Station, Laramie.

Financial statistics of the farmers' institutes for the year ended June 30, 1913.

State or Territory.	Funds appropriated.		Cost of institutes.		Appropriation for the season 1914.
	By the State.	By the college and received from other sources.	Total cost.	Cost per session.	
Alabama.....	\$600.00	\$1,000.00	\$1,600.00	\$36.36	\$1,600.00
Alaska ¹.....	.....	.....	.....	.....	.....
Arizona.....	2,500.00	398.88	2,898.88	161.05	4,400.00
Arkansas.....	4,000.00	200.00	4,200.00	87.50	3,750.00
California.....	15,000.00	.....	15,000.00	40.00	25,000.00
Colorado.....	2,500.00	2,500.00	5,000.00	43.48	.....
Connecticut.....	900.00	200.00	1,050.00	16.40	.....
Delaware.....	1,000.00	1,000.00	1,150.00	17.96	600.00
Florida.....	7,500.00	.....	7,500.00	40.32	10,000.00
Georgia.....	25,000.00	.....	25,000.00	125.00	.....
Hawaii ².....	.....	.....	.....	.....	.....
Idaho.....	4,000.00	1,000.00	5,000.00	28.90	12,500.00
Illinois.....	27,650.00	.....	27,650.00	28.80	24,550.00
Indiana.....	10,000.00	13,300.00	21,000.00	15.12	10,000.00
Iowa.....	7,559.21	39,818.63	39,987.80	37.58	.....
Kansas.....	16,650.00	7,435.00	24,085.00	23.82	22,400.00
Kentucky.....	20,000.00	1,500.00	10,866.13	33.95	20,000.00
Louisiana ¹.....	.....	.....	.....	.....	.....
Maine.....	2,300.00	.....	1,050.00	20.19	2,300.00
Maryland.....	6,000.00	.....	5,437.86	35.54	6,000.00
Massachusetts.....	6,000.00	.....	2,411.51	15.65	6,000.00
Michigan.....	8,500.00	400.00	8,900.00	7.21	.....
Minnesota.....	23,000.00	3,625.00	26,557.09	55.67	23,000.00
Mississippi.....	7,500.00	1,200.00	8,700.00	14.26	.....
Missouri.....	8,750.00	.....	8,750.00	17.09	.....
Montana.....	10,000.00	.....	10,000.00	36.76	10,000.00
Nebraska.....	17,500.00	.....	17,500.00	28.55	25,000.00
Nevada ¹.....	.....	.....	.....	.....	.....
New Hampshire.....	1,200.00	.....	995.00	33.16	2,000.00
New Jersey.....	4,679.12	.....	4,679.12	32.95	.....
New Mexico.....	.....	500.00	.....	.....	.....
New York.....	38,000.00	.....	31,641.56	22.74	20,000.00
North Carolina.....	10,000.00	.....	10,000.00	10.75	12,500.00
North Dakota.....	6,000.00	1,185.00	5,769.00	53.91	6,000.00
Ohio.....	28,716.76	.....	28,716.76	15.70	26,400.00
Oklahoma.....	10,500.00	.....	10,500.00	8.67	5,000.00
Oregon.....	2,500.00	.....	2,500.00	22.12	2,500.00
Pennsylvania.....	22,500.00	.....	22,500.00	22.23	27,500.00
Porto Rico ².....	.....	.....	.....	.....	.....
Rhode Island.....	.....	700.00	546.12	15.17	.....
South Carolina.....	2,500.00	.....	2,200.00	10.47	.....
South Dakota.....	16,000.00	.....	16,000.00	20.02	20,000.00
Tennessee.....	.....	.....	.....	.....	.....
Texas.....	17,500.00	3,010.17	20,510.17	16.60	.....
Utah.....	10,000.00	775.00	10,000.00	53.48	10,000.00
Vermont ².....	.....	.....	.....	.....	.....
Virginia ².....	.....	.....	.....	.....	.....
Washington ².....	.....	.....	.....	.....	.....
West Virginia.....	6,332.02	.....	6,332.02	12.17	.....
Wisconsin.....	20,000.00	.....	20,000.00	26.04	20,000.00
Wyoming.....	.....	200.00	200.00	18.19	1,500.00
Total.....	430,837.11	79,947.68	474,384.02	22.99	360,500.00

¹ No institutes held.² No report.

Number of lecturers employed by the State directors of farmers' institutes and reports of proceedings published for the year ended June 30, 1913.

State or Territory.	Total number of lecturers on the State force.	Number of members of agricultural-college and experiment-station staffs engaged in institute work.	Number of days contributed to institute work by agricultural-college and experiment-station lecturers.	Number of State lecturers giving agricultural instruction at—				Reports of proceedings.	
				Teachers' institutes.	High schools.	Normal schools.	Common schools.	Published.	Number of copies.
Alabama.....								No.	
Alaska ¹								No.	
Arizona.....	15	15	72					No.	
Arkansas.....	10	10						No.	
California.....	25	10	153	6	5	1	4	Yes.	15,000
Colorado.....	34	34		14	5		5	No.	
Connecticut.....	42	20	30					Yes.	5,000
Delaware.....	15	4	41					Yes.	3,000
Florida.....	16	11	29				3	Yes.	1,500
Georgia.....	23	23	361	5				Yes.	500
Hawaii ²									
Idaho.....	15	7	210	1	10	1		No.	
Illinois.....	65							Yes.	50,000
Indiana.....	55	14	76					Yes.	2,500
Iowa.....								Yes.	3,000
Kansas.....	19	18	108	6	10	1	2	No.	
Kentucky.....	8	1		1	20			Yes.	
Louisiana ¹									
Maine.....	23	5	10					Yes.	4,500
Maryland.....	15	7	44					No.	
Massachusetts.....	62	18	29					No.	
Michigan.....	42	8	60					Yes.	12,500
Minnesota.....	15				6			Yes.	50,000
Mississippi.....	20	14	132	3	3	4	1	No.	
Missouri.....	17	8	15					No.	
Montana.....	17	11	250	3	5			No.	
Nebraska.....	52	18	101					Yes.	
Nevada ¹									
New Hampshire.....	13	6	30					Yes.	1,500
New Jersey.....	8	7						No.	
New Mexico.....	8	8	150					No.	
New York.....	75	20	80			12		Yes.	10,000
North Carolina.....	37	4	79					Yes.	35,000
North Dakota.....	12	8	39					Yes.	25,000
Ohio.....	44							Yes.	
Oklahoma.....	17	13		8	20	5		Yes.	5,000
Oregon.....		56	612	8	7	1	14	No.	
Pennsylvania.....	54	8	50					Yes.	7,500
Porto Rico ²									
Rhode Island.....	29	9	17				1	No.	
South Carolina.....	12							No.	
South Dakota.....	12							No.	
Tennessee.....								Yes.	3,000
Texas.....	17				5		5	Yes.	20,000
Utah.....	35	15	109	2	11		5	No.	
Vermont ²									
Virginia ²									
Washington ²									
West Virginia.....	18							No.	
Wisconsin.....	38	3	9					Yes.	50,000
Wyoming.....	2	2	54					No.	
Total.....	1,036	415	2,950	57	107	25	40		304,500

¹ No institutes held.

² No report.

Comparative statement of farmers' institutes.

State or Territory.	Appropriation.			Number of sessions.			Number of institutes.				Attendance.		
	1910-11	1911-12	1912-13	1911-12	1912-13	1910-11	1910-11	1911-12	1912-13	1910-11	1911-12	1912-13	1910-11
	\$1,300.00	\$1,600.00	\$1,600.00	54	44		28	33	25	3,681	5,115	5,049	
Alabama.....													
Alaska 1.....													
Arizona.....	1,381.24	1,650.00	2,898.88	124	18	18	51	63	9	6,779	9,355	22,131	
Arkansas.....	5,000.00	4,200.00	4,200.00	426	48	375	69	213	24	11,091	25,541	3,880	
California.....	10,750.00	15,000.00	15,000.00	272	375	103	103	107	160	34,038	57,063	39,718	
Colorado.....	5,239.00	5,159.00	5,000.00	233	115	100	105	105	73	15,117	29,380	15,729	
Connecticut.....	5,000.00	1,000.00	1,100.00	50	64	64	48	23	37	5,000	2,887	3,860	
Delaware.....	1,050.00	950.00	2,000.00	58	64	64	24	21	21	8,940	4,748	18,366	
Florida.....	7,500.00	7,500.00	7,500.00	64	186	133	113	36	87	20,060	21,870	23,330	
Georgia.....	10,500.00	7,500.00	25,000.00	103	200		67	103	120	10,960	21,870	23,330	
Hawaii 2.....													
Idaho.....	4,111.10	5,000.00	5,000.00	74	173		41	42	57	8,991	11,007	12,092	
Illinois.....	29,125.00	35,950.00	27,650.00	802	960	102	102	197	117	104,731	170,690	107,767	
Indiana.....	19,750.00	18,750.00	23,300.00	1,201	1,389	382	382	372	418	201,580	173,758	225,496	
Iowa.....	18,376.88	45,668.51	47,377.84	692	1,064	76	76	91	113	137,703	139,080	209,490	
Kansas.....	15,000.00	18,000.00	24,055.00	902	1,011	300	300	342	498	58,504	96,786	57,290	
Kentucky.....	15,000.00	16,000.00	21,500.00	341	320	212	212	119	79	78,790	10,474	17,200	
Louisiana.....	1,100.00						32			4,800			
Maine.....	3,000.00	3,000.00	2,300.00	184	52		44	119	42	4,808	7,304	3,582	
Maryland.....	6,000.00	6,000.00	6,000.00	134	153	55	55	54	58	13,960	18,355	91,492	
Massachusetts.....	4,000.00	5,000.00	6,000.00	192	154	140	138	138	138	21,812	24,522	18,172	
Michigan.....	8,500.00	10,000.00	8,900.00	1,218	2,254	491	491	445	474	141,453	131,324	138,944	
Minnesota.....	20,985.00	26,054.37	26,625.00	665	477	218	218	226	138	114,446	103,192	177,306	
Mississippi.....	10,000.00	17,900.00	8,700.00	398	610	205	205	233	362	46,830	48,842	121,026	
Missouri.....	15,000.00	8,750.00	8,750.00	463	512	170	170	246	268	94,077	88,048	92,167	
Montana.....	10,000.00	10,000.00	10,000.00	304	272	85	85	140	102	11,973	21,048	18,067	
Nebraska.....	15,434.80	18,300.00	17,500.00	635	613	148	148	207	205	63,270	119,199	128,057	
Nevada 1.....													
New Hampshire.....	1,200.00	1,600.00	1,200.00	39	30	13	13	18	16	6,800	6,000	2,500	
New Jersey.....	3,000.00	2,500.00	4,679.12	131	142	47	47	45	47	8,195	7,710	10,937	
New Mexico.....													
New York.....	28,500.00	54,807.01	38,000.00	1,200	1,382	340	340	351	411	138,131	116,311	115,084	
North Carolina.....	7,500.00	9,530.00	10,000.00	940	930	32	32	463	455	49,989	57,426	59,536	
North Dakota.....	9,493.24	31,400.00	27,155.00	124	107	87	87	11	94	41,317	16,550	8,683	
Ohio.....	22,000.00	31,400.00	28,716.76	1,705	1,880	323	323	341	340	376,390	397,845	398,215	
Oklahoma.....	5,000.00	10,500.00	10,500.00	831	1,210	142	142	545	504	376,390	71,622	38,922	
Oregon.....	3,000.00	6,100.00	2,500.00	115	113	35	35	12	12	18,520	10,633	13,229	
Pennsylvania.....	25,500.00	25,500.00	22,500.00	1,046	1,012	221	221	226	210	162,809	154,841	128,008	
Porto Rico 2.....	430.18	600.00	700.00	32	36	23	23	27	20	2,640	2,595	2,800	
Rhode Island.....	11,197.27	3,500.00	2,500.00	329	210	78	78	187	105	27,000	3,210	35,000	
South Carolina.....													
South Dakota.....	10,469.76	13,000.00	16,000.00	481	799	116	116	178	397	13,100	55,246	85,957	

Tennessee.....	5,000.00	5,000.00	93	.....	42	81	.....	4,142	10,000	.....
Texas.....	5,000.00	17,500.00	744	1,235	292	714	1,108	23,360	44,982	327,008
Utah.....	6,000.00	11,000.00	466	187	49	250	1,103	5,945	66,208	9,523
Vermont.....	2,750.00	3,000.00	68	.....	50	34	.....	7,660	8,269	.....
Virginia.....	8,000.00	10,000.00	.....	.....	55	.....	.....	6,000	.....	.....
Washington.....	8,500.00	10,000.00	216	.....	34	68	.....	5,578	16,505	.....
West Virginia.....	8,000.00	8,203.20	510	520	88	102	104	28,100	37,543	43,052
Wisconsin.....	20,000.00	20,000.00	758	768	178	176	179	113,666	118,306	112,007
Wyoming.....	1,737.54	1,000.00	2	11	2	1	6	676	121	546
Total.....	432,663.47	533,972.09	19,430	20,640	5,889	7,598	7,926	2,291,857	2,549,199	2,897,391

1 No institutes held.

2 No report.

[illegible]

3 No data.

No report.

1 No extension work.

	2	36	2	30	20	3,000	4	17	28	10,000	3	750	30	35,790	120
Colored.....	2														
North Carolina.....	16														
North Dakota.....															
Ohio.....			15		490		11	25	121	20,000	2	53			
Oklahoma.....			14	78	78	28,287	15	412	119	70,970	7	427	656		
Oregon.....	1	158	44	352	102	27,218					1	2			
Pennsylvania.....	8						5	2	12	1,000					
Porto Rico.....															
Rhode Island.....	2		2								2				
Colored.....	6	90		60	15	5,000									
South Carolina ³															
South Dakota ¹															
Tennessee.....			5				5				1				
Texas.....	125		6				16	50	140	100,000	2	600		18,000	
Utah.....			8	187			3	23	24	16,921	2	200			
Vermont ¹															
Colored.....	2														
Virginia ¹															
Washington ²															
West Virginia.....	4	547			28	450	9	3	77	2,134	2	325	77	15,206	
Wisconsin.....	5	1,500					13	150	103	32,225	6				
Wyoming.....															
Total.....	298	4,995	1,933	7,888	6,154	4,012	175	1,193	1,244	491,519	113	457	2,057	179,133	

¹ No extension work.² No report.³ No data.⁴ Work of 18 institute lecturers included.

Statistics of agricultural extension by the agricultural colleges of the United States for the year ended June 30, 1913—Continued.

State.	Informal teaching.											
	In demonstration work.											
	In fields.				In animal husbandry.				In home economics.			
	Num- ber en- gaged.	Days of service, visited.	Num- ber of places visited.	Number of persons in at- tendance.	Num- ber en- gaged.	Days of service, visited.	Num- ber of places visited.	Number of persons in at- tendance.	Num- ber en- gaged.	Days of service, visited.	Num- ber of places visited.	Number of persons in at- tendance.
Colored ¹ .	Alabama.											
	Alaska ² .											
	Arizona.											
	Arkansas ² .											
	California.											
	Colorado ¹ .	1	300	20	2,500	1	300	20	2,500			
	Connecticut.	3	30	8	480							
	Delaware.	4	120	75								
	Florida.	1	200									
	Georgia.	6	6	5	115							
	Hawaii ³ .	70	14,000	42,000	210,000	1	150	45	270	1	7	7
	Idaho.	3	225	225	2,025	2	225	290		1	30	20
	Illinois.	35								14	382	360
	Indiana.	3	79	35	5,954	3	21	7	125	2	103	44
	Iowa.	8	160	60	8,000	3	120	40	6,000	3	330	107
	Kansas.											
	Kentucky.											
	Louisiana.	4				1				3		
	Maine.											
	Maryland ¹ .	4	1,200									
	Massachusetts.											
	Michigan.	3				3						
	Minnesota.	4				1						
	Mississippi.	3				1				3		
	Missouri.	2	27	22		1	8	8				
	Montana.	2				14	111	42	303,550			
	Nebraska.	2										
	Nevada ¹ .	5	1,500									
	New Hampshire.	4	14	14	7,780	4				1		

[illegible]¹ No extension work.

² No report.

³ No data.

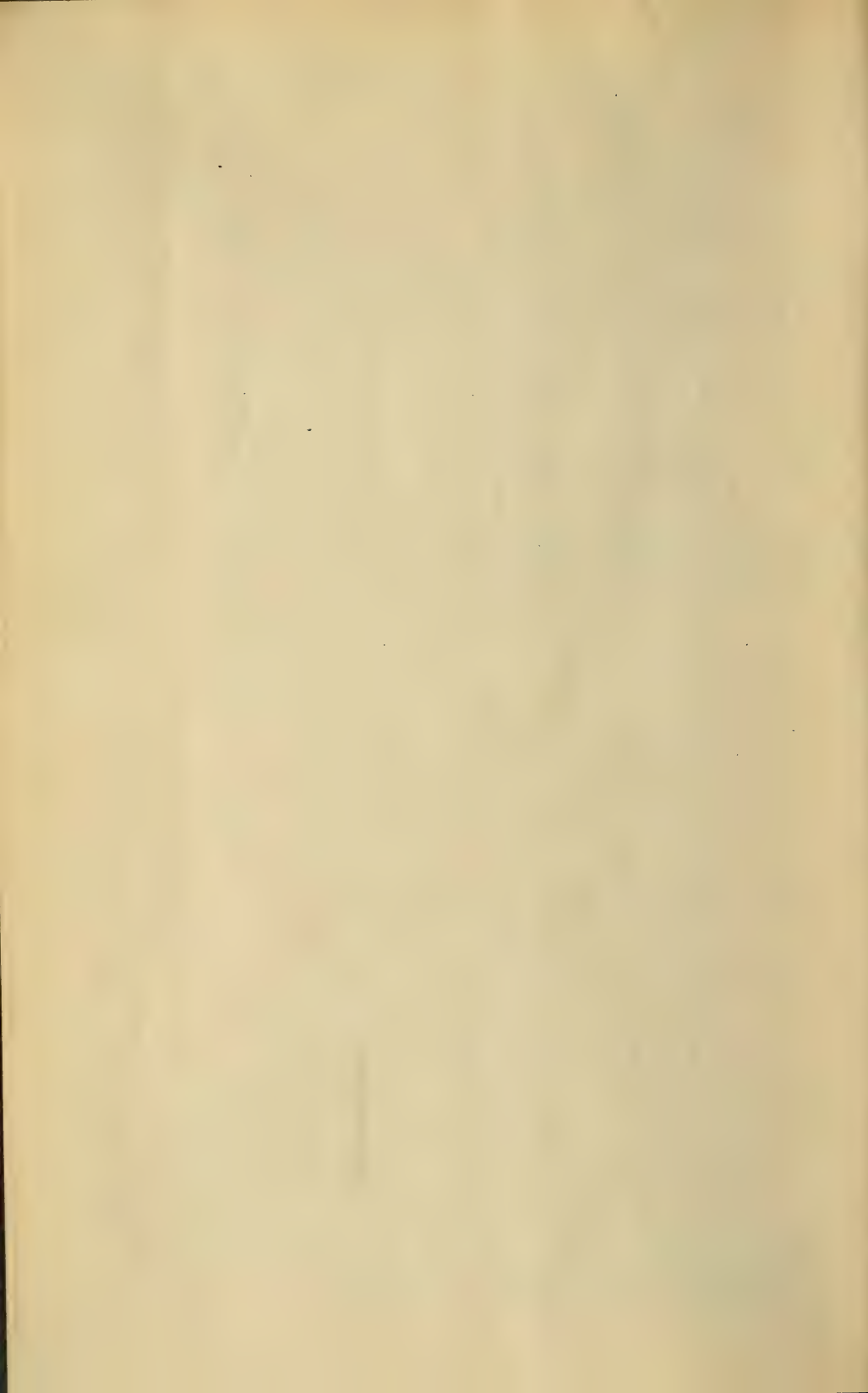
⁴ Work of 18 institute lecturers included.

TO

Colored.....	413	1,079	102,323	3,443	1,275	19	124	663,316.00	160,404.57	166,783.63	990,504.20	761,113.53	718,835.00
North Carolina.....	25	50	4	94		8		1,200.00	600.00	7,000.00	8,300.00	8,800.00	26,000.00
North Dakota.....			20	320		8		6,000.00	1,185.00	7,500.00	14,685.00	14,685.00	35,000.00
Ohio.....			26	186				40,000.00			40,000.00	40,000.00	35,000.00
Oklahoma.....	52	52	1	11				10,350.00			10,350.00	10,350.00	13,800.00
Oregon.....	4		6	24				2,500.00			2,500.00	2,500.00	32,500.00
Pennsylvania.....			9					17,000.00	9,100.00	900.00	21,000.00	21,000.00	14,180.00
Porto Rico.....			15	90				12,000.00			12,000.00	12,000.00	
Rhode Island.....								3,000.00	500.00	500.00	4,000.00	4,000.00	3,000.00
Colored.....	2	108										277.69	
South Carolina ³													
South Dakota ¹	2	2	3	82					880.00		880.00		
Tennessee.....			8	12				9,000.00	60,000.00	63,875.00	132,875.00	132,875.00	20,000.00
Texas.....	20	20	8	120		2	20	10,000.00			10,000.00	10,000.00	16,000.00
Utah.....													4,000.00
Vermont ¹										3,111.87	3,111.87	3,111.87	4,725.00
Colored.....		4											
Virginia ¹													
Washington ²	30	100	8	256	7			15,000.00	4,000.00	7,500.00	26,500.00	21,500.00	30,000.00
West Virginia.....	52	416	32		70			40,000.00	4,400.00	5,600.00	50,000.00	50,000.00	50,000.00
Wisconsin.....	7	7											3,500.00
Wyoming.....													
Total.....	413	1,079	102,323	3,443	1,275	19	124	663,316.00	160,404.57	166,783.63	990,504.20	761,113.53	718,835.00

¹ No extension work.² No report.³ No data.

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BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE



No. 84

Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.

April 16, 1914.

EXPERIMENTS WITH UDO, THE NEW JAPANESE VEGETABLE.

By DAVID FAIRCHILD, *Agricultural Explorer in Charge of the Office of Foreign
Seed and Plant Introduction.*

INTRODUCTION.

A decade has passed since the udo of Japan was first proposed as a vegetable to be grown by Americans. This is a short time for the introduction of a new vegetable, when one considers that it means simply that at ten different times experimenters have had a chance to taste its blanched shoots. But it is appropriate now that there be put in print some account of the experiences which various experimenters have had with this new vegetable.

Enough data are at hand for the production of an extensive bulletin on the udo, but, as much yet remains to be done, the important conclusions regarding its culture can be stated in a few paragraphs for the guidance of those who are interested in trying this new vegetable.

The writer first published, in 1902, a short account of the udo which he wrote in Japan while traveling as Mr. Barbour Lathrop's explorer¹ and before he had had any opportunity to experiment with the plant in America. Necessarily that account lacks any background of personal experience with the difficulties of cultivation.

Since 1906 the writer has had growing on his own place in Maryland just such a patch of udo as he is encouraging others to plant. (Figs. 1 and 2.) Each spring he has had the pleasure of experimenting with it in his kitchen, as well as of blanching it in the garden, and he can speak now regarding it with a degree of confidence not possessed heretofore. As a commercial proposition he has had only the chance of watching an experiment in California made by a large asparagus grower on the Sacramento River, who has now for three years been growing several acres of udo and has shipped crates of it to the eastern market, where, as was to be expected, he has found commission merchants slow to take it up. (Figs. 3 and 4.)

¹ U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 42, 1903, pp. 17-20.

NOTE.—Results of experiments in Maryland. Gives methods of cultivation, preparing, and cooking. Adapted to New England, the Atlantic States as far south as the Carolinas, the rainy region of Puget Sound, and the truck sections of California about Sacramento.



FIG. 1.—Plant of udo at "In the Woods," Chevy Chase, Md., Oct. 12, 1909, from seed planted in the spring of 1906, showing the ornamental character of the growth.

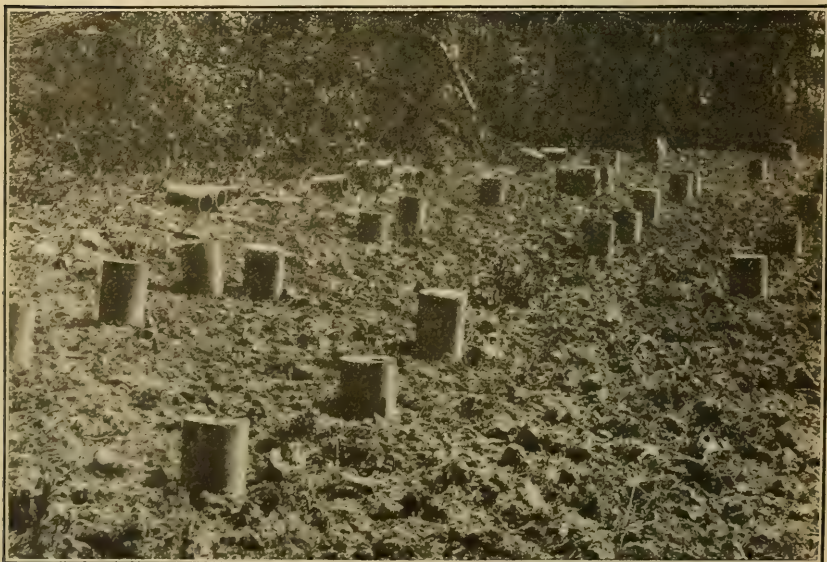


FIG. 2.—Field of udo at Chevy Chase, Md., showing draintiles used to blanch the shoots in the spring.

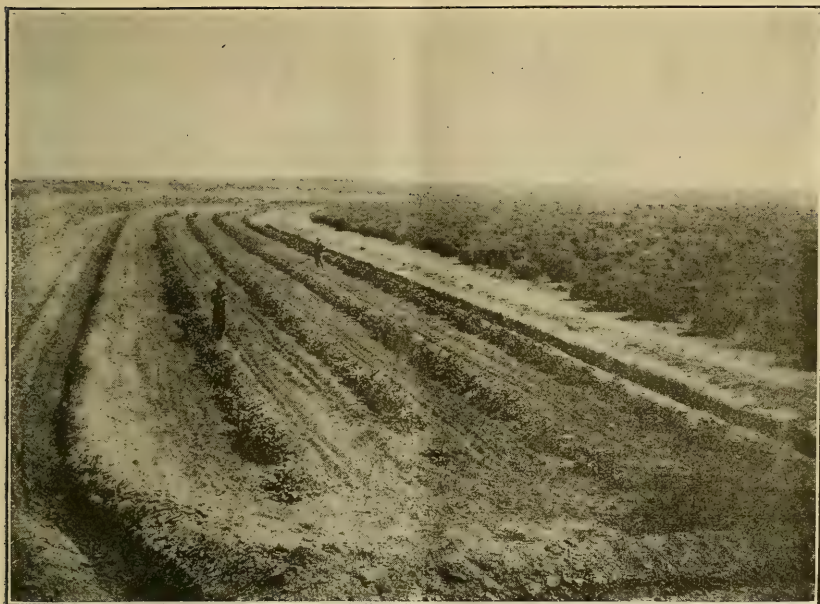


FIG. 3.—The first field of commercial udo in the United States, on the asparagus farm of Mr. M. E. Meek, Antioch, Cal.

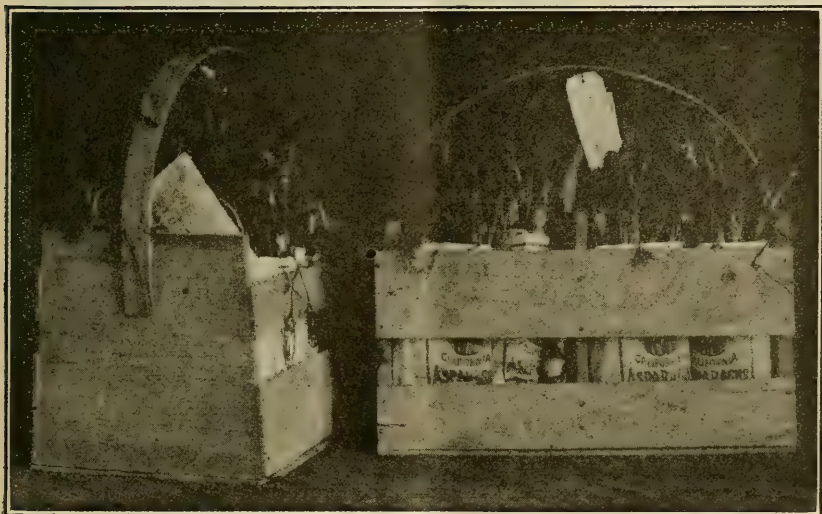


FIG. 4.—A crate of udo as it appeared after being shipped from Antioch, Cal., to Washington, D. C. The shoots were blanched by mounding up the soil, and many of the tips were green from exposure to sunlight above the mounds. Though slightly discolored, these were of good quality when prepared for the table.

There is no doubt that the udo is worthy of adding to our list of spring vegetables, for it is easily grown, its shoots are readily blanched, and it requires little care. A patch of it can be forced every spring for at least six years, and probably much longer. When properly prepared its blanched shoots are delicious; they have their own characteristic flavor, can be prepared for the table in a great variety of ways, and are keenly appreciated by people of discriminating taste. Space for space, udo will yield about the same amount of food for the table as asparagus and will be ready for use at about the same time in the spring. Possibly more labor is required to blanch the shoots of the udo than those of asparagus, but the udo is probably somewhat easier to take care of and yields sooner.



FIG. 5.—Plantation of udo one season from seed at the Arlington (Va.) Field Station, 1905.

As an ornamental, udo has been known to nurserymen for twenty years or more under the name of *Aralia cordata* Thunb. It might be termed a rank-growing, shrubby perennial with a large, fleshy rootstock (fig. 5). It dies down each fall after the first frost and comes up again, much as asparagus and rhubarb do. It grows to a height of 10 feet or more if on rich soil, producing a very ornamental mass of large green leaves, and, in the late summer, long, loose flower clusters, sometimes 3 feet in length. The flowers attract bees and flies in great numbers, and as a honey plant the udo would appear to warrant the attention of beekeepers (fig. 6). A field of udo is generally humming with insects.

EARLY EXPERIMENTS WITH UDO.

Siebold and Zuccarini,¹ in their *Flora of Japan*, called special attention as long ago as 1835 to the good qualities of the udo as a vegetable and recommended it for introduction into Europe, with



FIG. 6.—Flowers and fruit of the udo. The flowers are visited throughout the season by honeybees and flies, and the dark fruit clusters are ornamental.

the remark that “the young shoots form a delicious vegetable,” as follows:

This plant probably came from China, where it is employed as a sudorific; it is cultivated throughout Japan in the gardens and as a field culture.

¹ Siebold and Zuccarini. *Flora Japonica*, vol. 1, p. 57, 1835.

It is cultivated essentially for its root, which has an agreeable flavor, aromatic and bitter, and is eaten in winter prepared as we do the scorzonera (*S. hispanica* L.). The young shoots form a delicious vegetable.

As the plant grows well all over Japan, it will acclimate itself quite as well to our gardens; and this is why, cultivated with us, it may increase the number of our fresh vegetables by the addition of one which is good, wholesome, and nourishing. (Free translation.)

In that remarkable book by Paillieux and Bois, *Le Potager d'un Curieux*,¹ the authors give their experience with udo at their gardens near Crosnes. They experienced such difficulty in raising the plant from seed that they concluded, quite erroneously, as we have discovered, that udo seed must be sown as soon as mature or it will not germinate.

After several attempts to get living plants, dating from 1879, they were finally able to secure 10 of them. These grew very satisfactorily in their garden and, according to their report, they obtained, by blanching, very appetizing-looking shoots, resembling those of medium-sized asparagus. Unfortunately, the taste did not strike them favorably. They objected to the faint suggestion of turpentine and predicted the failure of udo in Europe.

How extensive the trials of Paillieux and Bois were the writer has not ascertained, but from his own experience he realizes how easy it is to form an unfavorable impression regarding the flavor of a new vegetable, and, judging from seven years of trial, in which he has submitted udo to the judgment of a great many people, he believes it is fair to conclude, since no recipes and only the barest details are given in their report, that the culinary trials made by these authors were quite inadequate to do justice to its excellent qualities.

Notwithstanding the fact that raw potatoes, improperly blanched celery, raw asparagus, and raw beets are all most disagreeable to the taste, the tendency is to overlook this and to condemn raw udo, comparing it with blanched celery, when in reality it has too strong a flavor to be eaten without first preparing it for the table in the proper way.

RELATIVES OF UDO.

There are two native species of the genus to which the udo belongs which resemble it quite closely in appearance—the spikenard or petty morel of our rich woodlands (*Aralia racemosa* L.) and a California species (*Aralia californica* S. Wats.). The spikenard is said to grow in the shade to a height of 4 or 5 feet, but a plant which the writer has had in his experimental garden in full sunlight for four years has never grown more than 3 feet high. This plant flowers much earlier than *Aralia cordata*, about the middle of July

¹ Paris, 1899, 3d ed.

instead of in September, and is altogether a much smaller plant. The root is said to be pleasant to the taste and was used as an ingredient of homemade beers in colonial times. The writer has never had an opportunity to blanch the shoots of the plant and test them. The California species is considerably larger than the spikenard and has leaves which are of a thicker, more leathery character than either the udo or the spikenard. In Maryland a plant of this species has lived through the mild winter of 1912-13, but it gives the impression of being distinctly not hardy there. It has not yet flowered and is not large enough to furnish shoots for comparison with the Japanese species. As material for breeding, these American forms, and possibly the wild sarsaparilla (*A. nudicaulis* L.), are promising, and there is room here for an interesting piece of breeding work, since it is the vegetative portion of the plant which is used and asexual methods of propagation are a success. No crossing of these species seems to have been attempted.

VARIETIES OF UDO.

When first introduced into America as a garden vegetable there were supposed to be two varieties only, the Kan udo and the Moyashi udo. Although grown side by side, there never appeared to be any marked difference between these two kinds, and the writer is convinced that they are identical varieties, Kan udo being seedling udo and Moyashi udo simply forcing udo. Much the same distinction exists between sea kale from seed and sea kale "crowns."

Since this first introduction, the writer's attention was called by Prof. Y. Kozai, director of the Imperial Agricultural Experiment Station, Nishigahara, Tokyo, Japan, to the fact that in Japan what are really believed to be distinct strains do exist, and these have been given distinctive names. Through the kindness of Prof. Kozai these varieties were introduced and are now growing in America. They are S. P. I. Nos. 33250, "Yozaemon, red, early"; 33251, "Hanza, late"; 33252, "Fushiaka, node red, midseason"; 33253, "Shiro, white, very early"; 33254, "Nakate, Usu-Aka, rosy, midseason"; and 33255, "Kan udo, red, extra early." The writer has grown these and forced them once only, and they appear to be very similar in appearance, but whereas seedling or Kan udo in this latitude is ready to cut in April, the Hanza and Fushiaka varieties are at least three weeks or a month later. The Yozaemon has produced its shoots at almost the same time as the Kan udo. The two later starting strains will prolong the cutting season well into the middle of May in the latitude of Washington, D. C., which will be a great advantage, and it is probable that other characteristics will be discovered as experimenters become familiar with these strains.

METHOD OF CULTURE.

Much remains to be done in the working out of the most inexpensive methods of cultivating udo. Conditions of labor and materials are so different here from those in Japan that the methods of the Japanese have to be adapted to our own circumstances. The climate in America, at least in the Eastern States, is so different from that of Japan that methods of forcing used there are not applicable here.

As a home garden vegetable the experience of the past 10 years indicates that the udo, when once started, is a very easy plant to grow. Amateurs have experienced some difficulty in growing udo from seed, but anyone with greenhouse or cold-frame facilities should have no difficulty with fresh seed if it is sown one-fourth inch deep



FIG. 7.—Young udo plants as distributed to experimenters. Seedlings from seed planted in February should attain this size by the first of June.

in March or April in what is known as screened potting soil, consisting of 1 part loam, 1 part leaf soil or mold, and 1 part sand. In two or three weeks the seeds should be up. From the flats, the young seedlings can be planted out in the ground as soon as they are 3 or 4 inches high, or they can be potted off and later set out in the field (fig. 7). Seedlings started in boxes or flats in March will often grow 4 or even 6 feet tall the first year and will flower freely if not prevented from doing so, as they should be, by cutting or pinching out the round flower buds in midsummer. Where the question is not one of propagating a horticultural strain, the seedling method of propagation is undoubtedly the best.

Where, however, it is desired to perpetuate a particular strain, udo plants may be grown from cuttings of the green shoots. To do

this, terminal shoots should be taken when they are three-eighths of an inch in diameter and cut 5 inches or more long, care being taken to make the cut just below one of the joints, or nodes, in order to insure that the cuttings form a proper callus. In California, the head gardener of the State University, Mr. Mansell, got 80 per cent of his cuttings so made to grow satisfactorily. He took them in late summer or early fall and put them in clean sand. The writer has rooted cuttings of this kind in garden soil in Maryland.

While it is possible that cuttings of the root might grow, the writer's experiments with them have been failures, at least unless a bud from the base of the stem was included in the cutting, in which case it grew satisfactorily.



FIG. 8.—General view of one-half acre plantation of udo at the Yarrow Field Station, near Rockville, Md. The plants set from thumb pots in the spring here averaged from 2½ to 4 feet high in late summer.

The udo is a coarse feeder, with great succulent roots which travel rapidly through loose, rich soil. They can consume astonishing amounts of nitrogenous manures and turn them into succulent shoots. Planting udo on poor, dry lands is not recommended, for, though it would probably live, it would make no growth there. A specially constructed bed, such as is often made for asparagus, is, however, not necessary.

Three and a half feet apart is close enough for plants of the udo to stand, for as they grow older the crowns become at least a foot across. On very rich soil the writer has found 4 feet not too great a distance. When grown even with this space between them the plants will touch each other and make horse cultivation impossible late in the summer. (Fig. 8.)

Seedling plants have often produced by the following spring roots large enough to give a small crop of shoots, but it is advisable to delay cutting the crop until the second year in order not to weaken the plants at first—following in this practice that usual with asparagus.

THE BLANCHING OF THE SHOOTS.

The stems of the udo when green are rank in flavor, and although the green shoots when pulled, peeled, and stewed are said to make excellent greens, it is the blanched shoots first produced in the spring that form the table delicacy. The blanching of these shoots has been done in a variety of ways. At first the method followed was that of mounding up the earth over each plant in early spring, but in this climate it was found that the late frosts make the soil too cold, and



FIG. 9.—Udo planting at Baddeck, Nova Scotia, showing on the right two mounds of earth which cover plants which were cut down in midsummer. The shoots blanched under these mounds were of excellent quality. While successful in the cool summer of Nova Scotia, this method will probably not be practicable in warmer climates.

the shoots are slow in coming through it. (Fig. 9.) In California, however, on the asparagus lands near Antioch, on the Sacramento River, Mr. W. H. Meek has produced excellent udo by mounding up the hills, much as he does those of asparagus; but there the soil is almost as light as sawdust.

A very satisfactory method for blanching udo in a small home garden is to put over each hill before growth starts in the spring a large draintile which has one end plugged with a cement cap or covering. The shoots coming up inside of the tile are well blanched, and this method has the advantage of making it possible to examine the shoots at any time to see how they are coming along. It has at least one disadvantage, however, in that the shoots have a tendency to leaf out and produce a number of unopened leafstalks which take

away from the robust growth of the shoots. A method which has obviated this defect in using tiles is to put around each hill a deep box or small half cask from which the bottom has been removed and fill it with light sand or such a light material as sifted coal ashes. Shoots which come up through such a medium are almost free from the elongated leafstalks which are developed when the shoots are produced in the dark air chambers under the tiles.¹ Care must be taken in any method of mounding up or filling in dirt or ashes over the crowns that the shoots do not break through into the sunlight,



FIG. 10.—The blanched shoots from a single crown of udo from which the draintile has just been removed. Note the slender leafstalks rising from the main stems. This forms an objection to the use of the draintile or any method of forcing in a closed air chamber.

for as soon as they do this they become green and take on a rank, objectionable flavor.

Properly grown udo shoots produced from 3-year-old plants should be from 12 to 18 inches long and 1 inch to 1½ inches in diameter at their bases (fig. 10). Such shoots are tender throughout, with no trace of fiber except in the rather thick “bark,” which can be easily removed. Naturally, if one is impatient for the very first udo shoots,

¹ Thinking to overcome this difficulty, the experiment was made of filling the tiles with soil before inverting them over the crowns, but the plants refused to grow up through this soil.

he can cut them when only 6 inches long, but if he will wait he will be rewarded by getting shoots of somewhat astonishing proportions.

In point of season the udo crop in the latitude of Washington approaches that of asparagus. It is perhaps a few days earlier under the draintiles. If 6-inch instead of 18-inch shoots are satisfactory, a crop of udo can be taken ten days or two weeks earlier than asparagus.

Just as with asparagus, sea kale, and endive, udo can be forced by packing the roots together in a trench over a layer of heating manure, but this method makes a very expensive vegetable of it and would be resorted to only by the gardeners on large estates. Shoots can be produced in this way in March, and doubtless also in November or December. After the removal of the crop of udo shoots in the spring, the crowns of the plants should be completely uncovered and the plants allowed to grow normally throughout the summer, but they should not be permitted to flower unless seed is required, the flower clusters being pinched or cut back as they form. This latter is not a necessary precaution, but it tends to throw the growth of the plants into the roots and increase the size of the shoots for the table the following year.

PREPARATION FOR THE TABLE.

The flavor of udo is distinctly aromatic, like celery or parsnip, but different from either. When properly prepared it is one of the most delicious of vegetables, but unless properly cooked it is sure to meet with ridicule. The reason for this lies in the fact that its stems contain a resinous substance which gives them a decided flavor of pine when tasted raw. There are many people who never get farther than this first taste and condemn udo on the spot, forgetting how disagreeably raw vegetables often taste.

It is a simple culinary practice to boil strong-flavored vegetables in two (or even three) waters, and this is advisable as a general recommendation, although when used for soup it does not appear to be always necessary. An hour's stay in ice water will remove this resin from the shoots, provided they are cut into thin slices or shavings.

Little is known regarding the food value of udo further than that analyses show it to have about the same dietetic value as celery or asparagus. The Chinese, who are prone to ascribe mysterious properties to many of their foods, have given to udo, which they call Dotooki, Dokii quatz, or Dosjen, medicinal properties which are more curious than probable.

RECIPES.

The following recipes for preparing udo are recommended:

Udo on toast.—Peel the shoots and drop them into cold water. Cut them into 4-inch lengths. Boil them in salt water for 10 minutes, then change the water, adding a fresh quantity of salted water and boiling until quite soft.

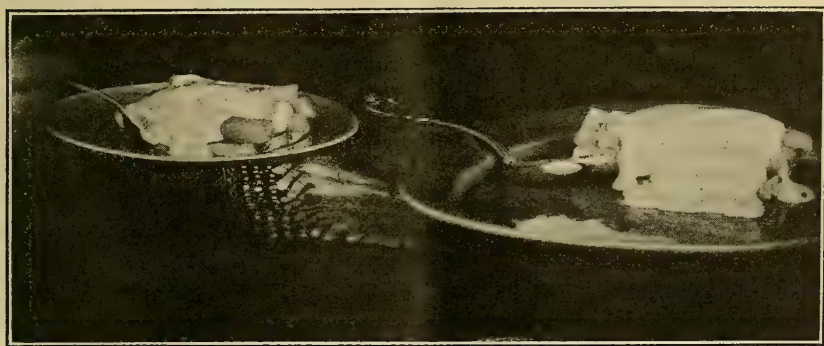


FIG. 11.—Udo on toast with cream sauce. The entire shoot can be eaten.

Prepare a white sauce, such as is used for cauliflower or asparagus, put the udo in it, and allow it to simmer until thoroughly soft. Serve on toast (fig. 11) in the usual way. If there is too much of the pine flavor, as there may be if the shoots are not thoroughly blanched, a second change of water will remedy this.

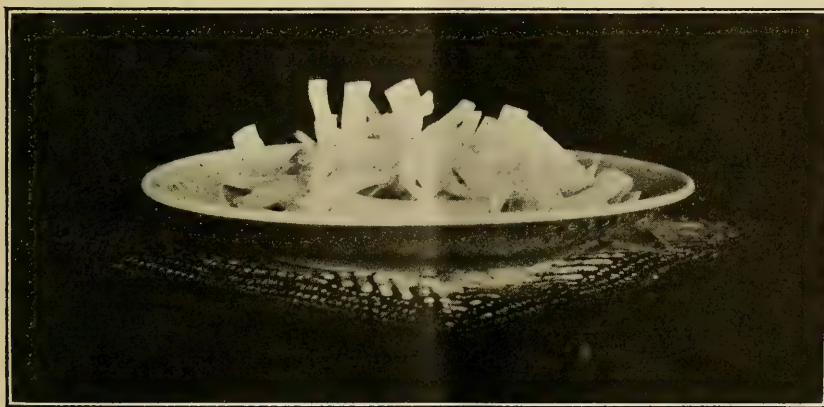


FIG. 12.—Udo as a salad. The shoots have been peeled and cut into thin shavings and left in ice water until the strong flavor has been removed, then dressed with a French dressing.

Udo salad.—Peel the shoots, cut them into 3-inch lengths, and then split them into thin shavings, letting these fall into ice water as they are made. Allow them to soak in the water for a half hour or an hour, so as to remove the resinous material in them. Serve with a French dressing of pepper, salt, oil, and vinegar. Do not dress the shavings until just before serving, as they become stringy on standing in oil. (Fig. 12.)

Udo soup.—Remove the skin from the shoots. Cut in pieces one-half inch long and wash thoroughly in cold water. Cook until tender and mash through a colander. Add a pint and a half of milk, one-half pint of cream, two tablespoonfuls of butter, and one tablespoonful of flour, mixing the flour and butter until smooth. Season with pepper and salt. (Recipe for one bunch of udo; enough for five persons.)

CLIMATIC REQUIREMENTS OF UDO.

From the fact that udo is grown all over Japan, one might assume that it is adapted to a wide range of climate, but it must be borne in mind that Japan has an insular climate and that none of its plants are subjected to drought. The udo has done best in the moist regions of this country, especially in the New England States, Canada, and the Atlantic States as far south as the Carolinas, in the rainy region of Puget Sound, and in the trucking sections of California, about Sacramento. The fact that it dies down in the winter and can be covered makes it possible to grow it where temperatures go far below zero. A temperature of -17° F. for a few days has not injured it in the least.

DISEASES OF UDO.

Like almost every other plant, udo has its diseases. Dr. B. D. Halsted, of New Brunswick, N. J., has had trouble with his plants because a leaf spot (*Colletotrichum*?) attacked the foliage and did much damage. The writer discovered a soft rot of the roots which killed a number of apparently vigorous plants on the farm of the Department of Agriculture at Arlington, Va., the cause of which proved to be a sclerotium-producing fungus, the mature form of which has not yet been observed. These diseases, however serious they may seem, should not discourage the trial by thousands of Americans of this easily grown early-spring vegetable, which will thrive under so many and varied conditions.

REASONS FOR THE INTRODUCTION OF UDO.

The writer is not certain that from a purely money-making standpoint udo will prove superior in any detail or combination of details to vegetables which are already under cultivation in America, but it has a distinctive flavor, and many people are beginning to like it, as they have learned to like celery, asparagus, and eggplant. Notwithstanding its centuries of culture in the Orient, it is still a vegetable whose potentiality remains quite undetermined. It is highly desirable that many amateurs should experiment with it and the public get acquainted with it in order that a sufficient demand may be created to encourage growers to investigate it on a sufficiently extensive scale to determine whether it has any really economic advantages.

over such annual crops as celery or such perennial crops as asparagus. It has been estimated that when grown on a large scale it would require much less labor than celery and that it furnishes a crop from seed at least a year sooner than asparagus, and there may be other advantages which will appear during the long process of adaptation through which every new plant introduction must pass before it becomes a real factor in the diversification of our agriculture.

Udo has already won many adherents among those who care for new vegetables, and, although it can not by any means be said to be a well-known table vegetable, it has arrived at a point where it might be pushed by any careful, enterprising advertiser of fancy vegetables. It has been served successfully at large dinner parties in Washington and on the private tables of those who have their own gardens. It is winning its way steadily, as evidenced by the increased call for plants and the fact that importations of seed from Japan have become considerable, according to recent advices from an important nursery firm there.

In Europe, so far as the writer is aware, udo has not made any headway; but this is not to be wondered at when we consider the conservatism it must meet there. Mr. Philippe de Vilmorin, of the firm of Vilmorin-Andrieux & Cie., of Paris, admits, however, that udo is the one Japanese vegetable which deserves to be introduced into cultivation in France.





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(PROFESSIONAL PAPER.)

THE COST OF PASTEURIZING MILK AND CREAM.

By JOHN T. BOWEN, *Technologist, Dairy Division.*

INTRODUCTORY.

In the pasteurization of milk and cream there are two systems in use at the present time, known as the "holder" and the "flash" processes. The holder process consists in holding the milk or cream for about 30 minutes after it has been heated to the pasteurizing temperature of 140° to 150° F., either in the same apparatus in which the pasteurization takes place or in separate holding tanks arranged for the purpose, after which it flows to the coolers. In the flash or continuous process the milk or cream flows from the receiving tank to the pasteurizer, where it is heated to a temperature of from 160° to 165° F. in from 30 seconds to 1 minute, and from thence direct to the coolers, where it is cooled.

It is obvious that there is more heat required to pasteurize a given amount of milk or cream in the latter process than in the former; for example, assuming that the initial temperature of the incoming milk is 60° F. and that in the holder process it is heated to 150° F. and in the flash process to 165° F., then for every 1,000 pounds of milk to be pasteurized by each of these processes the actual number of heat units required to raise the temperature of the milk to the pasteurizing temperature is:

$$\text{B. t. u.}^1 = 1,000 \times 0.95^2 (150 - 60) = 85,500, \text{ holder process.}$$

$$\text{B. t. u.} = 1,000 \times 0.95 (165 - 60) = 99,750, \text{ flash process.}$$

It will be noted from the above figures that the flash process of pasteurization requires 16.6 per cent more heat to pasteurize a given

¹ B. t. u. (British thermal unit) is the quantity of heat required to raise 1 pound of pure water 1° F. at or near its maximum density, 39.1° F. For practical purposes, however, it may be considered the heat required to raise the temperature of 1 pound of water 1° F.

² The specific heat of milk is taken as 0.95. The specific heat of any substance is its capacity for absorbing heat compared with that of water taken as unity.

NOTE.—This bulletin deals with the cost of pasteurization from an engineering point of view. It contains desirable information for proprietors of creameries and milk plants and for designers and manufacturers of pasteurizing apparatus.

amount of milk than the holder process. Furthermore, the milk must be cooled through a correspondingly wider range. These figures, however, deal only with the heat absorbed by the milk, and do not take into consideration that radiated to the air and absorbed by the metal and other materials used in the construction of the apparatus.

TESTS OF MILK-PASTEURIZING APPARATUS.

The following tests were made on the pasteurizing equipment of five city milk plants. They were considered as representing average city plants. The pasteurizing equipment in each case consisted of heater, holding tank, regenerator, and cooler. In plants 1 and 2 the heater and regenerator were combined in one unit, and in plants 3, 4, and 5 they were separate. In plant 3 the regenerator was in the form of an ordinary tubular cooler, and the hot milk from the holding tank was pumped through the coils while the cold raw milk flowed over the tubes. In plants 4 and 5 the regenerators consisted of double-pipe arrangements, the hot milk flowing through the inner pipe and the cold milk through the outer and therefore surrounding the inner pipe.

The boilers were in good condition and were provided with exhaust steam feed-water heaters which heated the boiler feed water from an initial temperature of 60° F. to a final temperature of 180° F. The boiler pressure in all cases was approximately 80 pounds. The efficiency of the boiler and setting is assumed to be 50 per cent in all cases, which is believed to be a fair average. However, if there was a variation of 10 per cent in the estimated efficiency of the boiler and setting, it would affect the cost of pasteurization by approximately one-half of 1 per cent. It is further assumed that the coal cost \$4 per ton (2,240 pounds) delivered in the bunker and that it had a heat value of 12,500 B. t. u. per pound.

The condensed steam was caught as it came from the heater and weighed and its temperature taken, the average temperature being 180° F. The pressure of the steam entering the heater was reduced from the boiler pressure of 80 pounds gauge to from 3 to 5 pounds. Therefore, the heat absorbed in the heater per pound of steam supplied was $1,155 - (180 - 32) = 1,007$ B. t. u. For the sake of simplicity the heat absorbed in the heater per pound of steam supplied is taken as 1,000 B. t. u.

The temperatures of the milk were taken at each stage of the process and are recorded in Table 1, "Temperature balance." It will be noted from an inspection of the temperature balance that the cycle of operation consisted in starting with the initial temperature of the raw milk and raising its temperature to the pasteurizing point, about 145° F., then cooling the milk down to the temperature of the raw milk.

No account was taken of the cooling below the temperature of the milk in the receiving vat, as this had nothing to do with the pasteurizing cycle.

Based on the foregoing data and assumptions the following calculations are made:

TABLE 1.—Results of tests at five milk-pasteurizing plants.

HEATING.

	Plant number.				
	1	2	3	4	5
Time of operation.....hours..	4.366	3.216	2.0	4.0	3.6
Amount of milk pasteurized.....pounds..	40,577	20,236	7,628	29,799	22,055
Amount of steam used in the pasteurizer, pounds.....	2,258	1,383	263.5	1,128	572.7
Heat in the steam supplied direct from the boiler to pasteurizer.....B. t. u..	2,601,595	1,593,405	305,499	1,299,542	659,796
Heat in the steam required to drive the pasteurizing equipment.....B. t. u..	1,006,259	444,704	276,519	921,664	829,439
Total heat supplied by boiler for pasteurizing.....B. t. u..	3,607,854	2,038,109	582,018	2,221,206	1,489,235
Heat absorbed in the pasteurizer.....do..	2,258,000	1,383,000	263,500	1,128,000	572,700
Total boiler horsepower developed for pasteurizing.....B. H. P..	108.3	61.2	17.5	66.7	44.7
Boiler horsepower per hour developed for pasteurizing.....B. H. P..	24.8	19.0	8.75	16.7	12.4
Total heater horsepower consumed in pasteurizing.....B. H. P..	67.8	41.5	7.9	33.9	17.2
Heater horsepower per hour consumed in pasteurizing.....B. H. P..	15.6	12.9	3.9	8.5	4.8
Milk pasteurized per boiler horsepower, pounds.....	375	330	435	446	493
Milk pasteurized per heater horsepower, pounds.....	598	487	965	879	1,282
Coal consumed for pasteurizing, pounds....	578	326	93	355	238
Milk pasteurized per pound of coal, do....	70	62	82	84	93

COOLING.

Cooling water required in water section of cooler.....cubic feet..	1,697	960	219	317	.....
Refrigeration extracted by brine.....tons..	.48	.46	.206	1.70	.886

COSTS.

Capital invested in pasteurizing equipment (pasteurizers, vats, coolers, etc.)..	\$5,332.00	\$3,000.00	\$2,065.00	\$3,470.00	\$6,250.00
Interest per day on investment at 6 per cent per annum.....	.876	.493	.339	.570	1.027
Depreciation and repairs per day at 25 per cent per annum.....	3.652	2.055	1.414	2.380	4.281
Capital invested in mechanical equipment used for pasteurizing (engine, boiler, shafting, etc.).....	1,000.00	800.00	300.00	500.00	700.00
Interest per day on investment at 6 per cent per annum.....	.164	.131	.049	.087	.115
Depreciation and repairs per day at 10 per cent per annum.....	.274	.219	.082	.137	.192
Labor, for pasteurizing.....	3.500	1.750	1.500	3.000	3.000
Cost of coal at \$4 per ton (2,240 pounds)....	1.032	.582	.166	.634	.425
Cost of cooling water at 50 cents per 1,000 cubic feet.....	.848	.480	.109	.158	.009
Cost of refrigeration at \$1 per ton.....	.480	.460	.206	1.700	.886
Cost of pasteurizing daily supply of milk.....	10.826	6.170	3.865	8.666	9.935
Cost of pasteurizing one gallon of milk.....	.00229	.00262	.00436	.00251	.00387
Average cost for the five plants of pasteurizing 1 gallon of milk.....	.00313	.....	.....	.....	.....

TABLE 1.—Results of tests at five milk-pasteurizing plants—Continued.

HEAT BALANCE.

	1		2		3		4		5	
	Heat supplied.	Heat accounted for.	Heat supplied.	Heat accounted for.	Heat supplied.	Heat accounted for.	Heat supplied.	Heat accounted for.	Heat supplied.	Heat accounted for.
Total heat in steam supplied to pasteurizer.....	P. ct. 100.00	P. ct.	P. ct. 100.00	P. ct.	P. ct. 100.00	P. ct.	P. ct. 100.00	P. ct.	P. ct. 100.00	P. ct.
Heat returned by regenerator.....	43.86	.....	41.00	.....	151.87	.....	124.76	.....	264.27	.....
Heat remaining in liquid (condensed steam).....	.....	14.51	.....	14.51	.....	14.62	.....	14.64	.....	14.62
Heat required to raise temperature of initial charge of water.....	.....	1.92	.....	2.41	.....	5.56	.....	.....	.....	.....
Heat lost in holder.....	.....	11.79	.....	5.09	.....	5.38	.....	2.91	.....	12.42
Heat absorbed in regenerator by incoming milk.....	.....	43.86	.....	41.00	.....	151.87	.....	124.76	.....	264.27
Heat absorbed in cooler in reducing temperature to that of raw milk.....	.....	65.97	.....	64.98	.....	47.63	.....	65.58	.....	34.39
Loss in radiation, exclusive of holder.....	.....	5.81	.....	12.98	.....	26.80	.....	16.87	.....	38.57
Total.....	143.86	143.86	141.00	141.00	251.87	251.87	224.76	224.76	364.27	364.27

TEMPERATURE BALANCE.

	1 ¹	2 ¹	3 ²	4 ³	5 ⁴
Raw milk.....°F.....	63.50	57.86	59.40	54.00	47.60
Regenerator.....°F.....	.....	.....	131.30	107.50	124.10
Rise in regenerator.....°F.....	.....	.....	71.90	53.50	76.50
Per cent rise.....per cent.....	.....	.....	84.00	60.53	78.30
Heater.....°F.....	146.00	150.40	145.00	142.40	145.30
Rise in heater.....°F.....	82.50	92.54	13.70	34.90	21.20
Per cent rise.....per cent.....	.....	.....	16.00	39.47	21.70
Total per cent rise.....per cent.....	100.00	100.00	100.00	100.00	100.00
Holder.....°F.....	146.00	150.40	145.00	142.40	143.30
Drop in holder.....°F.....	8.00	4.24	2.25	1.33	3.90
Per cent drop.....per cent.....	9.70	4.58	2.63	1.50	3.99
Regenerator.....°F.....	138.00	146.16	142.75	141.07	141.40
Drop in regenerator.....°F.....	29.75	34.16	63.45	57.07	83.00
Per cent drop.....per cent.....	36.00	36.85	74.12	64.50	84.96
Cooler.....°F.....	108.25	112.00	79.30	84.00	56.00
Drop in cooler.....°F.....	44.75	54.14	19.90	30.00	10.80
Per cent drop.....per cent.....	54.30	58.57	23.25	34.00	11.05
Total per cent drop.....per cent.....	100.00	100.00	100.00	100.00	100.00

¹ Regenerator in heater.² Surface cooler used as regenerator.³ Direct expansion coils in cooler.⁴ Cooled entirely by refrigerated water.

ECONOMY IN USE OF REGENERATORS.

Referring to the heat balance for the foregoing plants in which regenerators, or heat exchangers, were used, it will be noted that in some cases the heat returned by the regenerator is considerably in excess of the total amount supplied by the heater. It should be borne in mind, however, that this heat is exchanged from the hot milk leaving the holder to the cold incoming milk, the heat supplied by the steam going to make up the losses; consequently the greater the efficiency of the regenerator the less heat is required from the steam. The hot milk from the holder is transferred to the cooler usually through the inner pipe of the regenerator; consequently

the milk entering the heater is thus heated, while that entering the cooler is partly cooled, the cooler proper reducing the temperature to the point desired. The function of the regenerator is therefore to economize heat by transferring the heat from the hot to the cold milk. The hot milk coming from the heater flows into the holding vat and is here held for about 30 minutes. It then flows through the regenerator to the cooler, where it is cooled by water and brine circulation, direct expansion of ammonia in the cooler pipes sometimes being used instead of brine.

Just the reverse is true in the case of the cold milk; that is, the cold milk comes from the receiving vat, where it is at a temperature of about 55° F., and goes through the outer coils of the regenerator, where it is heated by the returning hot milk. It is obvious, therefore, that any heat transferred from the hot to the cold milk represents just so much gain in economy. If it were possible to transfer all the heat in the hot milk above the initial temperature of the raw to the cold incoming milk after the first charge had been once heated to the pasteurizing temperature, the heater could be dispensed with entirely, and the pasteurizing would go on indefinitely. This would constitute, however, a theoretically perfect machine, which is an impossibility; but the more perfect the regenerative apparatus the less heat will have to be supplied by the heater. The heat balance in test No. 5 shows that it would have taken over two and a half times the heat had no regenerator been used.

In all of the foregoing tests the pasteurizing was done with live steam taken direct from the boiler but reduced in pressure to from 3 to 5 pounds. Subsequent tests show that the pasteurization could just as well have been done with exhaust steam, and by so doing a load of from 8.75 to 24.8 boiler horsepower could have been taken off the boiler plant except in plant 1, where the exhaust steam was utilized for making ice in an absorption ice plant.

Attention is invited to the saving obtained by the use of regenerators in the foregoing tests. The boiler horsepower per hour required for pasteurizing in tests Nos. 1, 2, 3, 4, and 5 was 24.8, 19, 8.75, 16.7, and 12.4, respectively. Without the regenerator, or heat exchanger, the boiler horsepower per hour required for pasteurizing would have been increased to 35.6, 26.78, 22, 37.5, and 45.1, respectively. Thus the average increase in fuel would have been 96.8 per cent, or practically doubled. In addition to the direct saving in fuel due to exchanging the heat from the hot milk coming from the holding tank to the cold raw milk on its way to the heater, there is an average saving in refrigeration of approximately 60 per cent, for it is evident that the heat taken out of the hot milk in the regenerator takes just so much work off the cooler. By referring to the temperature balance in the table it will be noted that the drop in temperature in the

regenerator varied from $29\frac{3}{4}^{\circ}$ to 83° F., an average of $53\frac{1}{2}^{\circ}$ F. In other words, the milk arrived at the cooler $53\frac{1}{2}^{\circ}$ F. lower in temperature than it would have done had no regenerator been used.

The regenerator is an efficient piece of apparatus when viewed from an engineering standpoint, but it has its disadvantages when viewed from the bacteriological standpoint, as it is difficult to keep absolutely clean and sterile unless given particular attention.

DEPRECIATION OF DAIRY EQUIPMENT.

Owing to the rough usage to which dairy apparatus is subjected, having to be taken apart for the purpose of thorough cleaning after each operation, and to the rapid development and improvement in this line of apparatus, it is assumed that about four years is its average useful life, at which time it is either worn out or antiquated and must be replaced. Therefore, it has been depreciated at the rate of 25 per cent per annum.

The mechanical equipment (engine, boiler, shafting, etc.) necessary for the operation of the pasteurizing apparatus and which has been depreciated at the rate of 10 per cent per annum covers only that part of the total equipment which is used for pasteurizing. In other words, the total value of the mechanical equipment of the plant is prorated among the various processes through which market milk passes in a modern city milk plant.

TESTS OF CREAM-PASTEURIZING APPARATUS.

Tests made on the pasteurizing equipment in creameries covered both the flash and the holder processes. The pasteurizing was also accomplished by using (1) live steam direct from the boiler, (2) exhaust steam from the engine or from steam-driven pumps, and (3) hot water heated by the exhaust steam from the steam-driven auxiliaries.

In calculating the heat absorbed by the cream in the following tests, the specific heat of cream is taken as 0.90. In this connection it is well to state that there seems to be very little known at the present time concerning the specific heat of cream. It does, of course, vary to a certain extent with its chemical and physical composition. At a certain point on the temperature scale its specific heat is greatly increased, apparently above unity. This is attributed, however, to the melting of the butterfat and a part of the absorbed heat being used to effect the change.

In Table 2 are given the results of tests on the pasteurizing equipment of four creameries. The tests were made under actual working conditions. In tests Nos. 1, 2, and 3 the pasteurizing was done by employing exhaust steam and in test No. 4 live steam was taken direct from the boiler through a reducing valve.

TEST NO. 1.

Referring to test No. 1, the pasteurizing was done with hot water which was heated by exhaust steam from five steam-driven turbine separators and five reciprocating steam pumps. The arrangement for utilizing the heat in the exhaust steam is illustrated diagrammatically in figure 1. As it was impracticable to put a back pressure on the small steam turbines used for driving the separators, as would be done if they were allowed to exhaust under water or into a milk heater, the arrangement shown was resorted to. The exhaust from the separators and pumps was piped into the box above the water level. The hot-water circulating pump took the water from the box and forced it through the internal tubular heater and back into the box. The spray pipe, located in the top of the box, above the water level, was

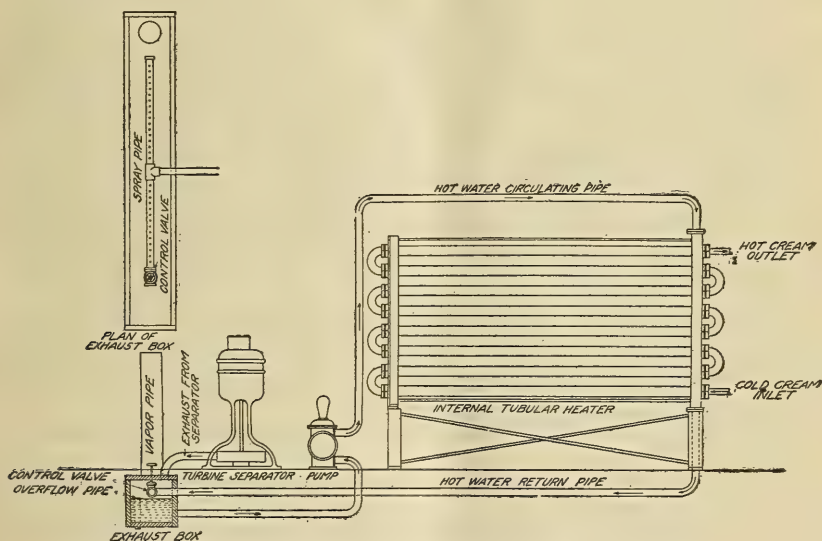


FIG. 1.—Elementary diagram of hot water pasteurizing equipment.

perforated with a large number of small holes through which the return water was sprayed. The heat contained in the exhaust steam was taken up by the water, the equipment acting on the principle of the jet condenser. There was a valve placed on the end of the spray pipe for controlling the temperature of the water. By opening this valve the return water was allowed to pour out into the box without absorbing much heat from the steam, while, on the other hand, if the valve was closed all of the return water was sprayed, thereby absorbing the maximum amount of heat. The temperature of the water was controlled very satisfactorily by this arrangement. There was an overflow pipe placed in the box, as indicated, which kept the water at a constant level by allowing the condensed steam to overflow into the sewer. There was a vapor pipe on one end of the box which

allowed the uncondensed steam to escape to the atmosphere. The exhaust box was built up of cypress lumber, being about 12 inches square by 14 feet long. The heat contained in the exhaust steam from the five steam turbine driven separators and five reciprocating pumps was sufficient for pasteurizing 17 per cent cream at the rate of 18,360 pounds, or 9.18 tons, per hour. This was actually done during the first hour of test. The initial temperature of the cream was 49.5° F., and it was raised to a pasteurizing temperature of 147° F., or through a range of 97.5° F.

As 1 boiler horsepower is equivalent to the evaporating of 34½ pounds of water from and at 212° F., the boiler horsepower per hour required for pasteurizing under the above conditions was 67.1. It is therefore obvious that had this exhaust steam been allowed to go to waste and live steam been taken direct from the boiler for pasteurizing, the boiler capacity of the plant would have had to be increased by this amount, viz., 67.1 horsepower. In other words, there was a saving in boiler capacity, by using the heat in the exhaust steam for pasteurizing, of 67.1 horsepower. As has been previously explained, it was necessary to employ some such arrangement as that illustrated in the diagram in order to avoid putting a back pressure on the turbine separators, although this arrangement entailed a loss of heat due to the double heat transfer from the exhaust steam to the water and from the water to the cream.

Assuming that the boiler and furnace efficiency was 50 per cent and that the coal used had a heating value of 12,500 B. t. u. per pound, then the fuel saved per hour with this arrangement is $\frac{67.1 \times 34.5 \times 970.4}{12,500 \times .50} = 359$ pounds. If the pasteurizing equipment is run 4 hours a day for 310 days in the year, the annual saving in fuel is $\frac{359 \times 4 \times 310}{2,240} = 198.7$ tons, which at \$4 per ton would amount to \$794.80. In addition to the fuel saved, there is a further saving due to the decreased boiler capacity of the plant.

It is evident that if the exhaust steam from the separators and pumps had been allowed to escape it would have been necessary to have taken live steam from the boilers for the purpose of pasteurizing, and this would have taken an additional 70-horsepower boiler, which would have cost approximately \$14.75 per boiler horsepower installed, or \$1,032.50. Figuring the interest on the money invested at 6 per cent per annum and depreciation and repairs at 10 per cent, there is a saving in addition to the fuel of \$165.45, making a total saving of \$794.80 + \$165.45 = \$960.25, to say nothing of the increased labor of firing the boiler. Adding this to the actual cost would bring the cost of pasteurizing 100 pounds of cream in this particular plant up to \$0.0512, or an increase of 12.3 per cent. The fuel cost,

however, is practically doubled when steam is taken direct from the boiler for pasteurizing instead of utilizing the exhaust steam. The steam pressure is reduced from boiler pressure to about 3 pounds by some form of reducing valve, consequently there is approximately as much heat in the exhaust steam from the engine, or steam-driven auxiliaries, as there is in steam taken from the boiler. The amount of fuel mentioned above is for pasteurizing, and is not to be confused with the total amount used in firing the boilers. In other words, it is the fuel required to evaporate in the boiler a certain amount of water which is used for the purpose of pasteurizing the cream. With this arrangement the pasteurizing was done with heat that would otherwise have been wasted, and furthermore it took a load of 67.1 horsepower off the boiler plant.¹

TESTS NOS. 2, 3, AND 4.

Tests Nos. 2 and 3 were also made with exhaust steam, but the arrangements were different from the foregoing, as the exhaust from the engines was piped directly into the heater. The only load on the engines at the time was the pasteurizers and the centrifugal cream separators, which amounted to very little. The exhaust steam available, however, was sufficient to operate the pasteurizers up to their full capacity.

Referring to the summary of the tests in Table 2 it will be noted that the fifth item, "Heat in steam required to drive pasteurizing equipment," is blank except for test No. 4. The reason for this is that the engine or steam-driven auxiliaries from which exhaust steam was used for pasteurizing are considered in the light of pressure-reducing valves, the mechanical power being, so to speak, a by-product. That is to say, there is a loss of heat in steam due to drop in pressure, and while the wire drawing of the steam through the valve will superheat the steam to a certain extent, the loss may be considered the same for the purpose of this paper, regardless of whether this drop is caused by passing through a pressure-reducing valve or through a steam engine. In test No. 4 the steam used for pasteurizing was reduced in pressure by a valve, consequently the energy represented by the difference in pressure and temperature of the steam before and after passing through the reducing valve is a clear loss. In neither case, however, was the heat lost due to drop in pressure of the steam available for heating the cream. The 380,800 B. t. u. in column 4 represents the heat in the steam at boiler pressure which was used in the engine for driving the pasteurizer, separator, shafting, etc., required in the process of pasteurizing, and as the exhaust from the engine was allowed to go to waste it is

¹ The use of exhaust steam for other purposes in milk plants is treated in Bureau of Animal Industry Circular 209.

obvious that the 380,800 B. t. u. represented so much additional heat over the exhaust-steam systems in tests Nos. 1, 2, and 3.

As stated above, in test No. 4 the pasteurizing was done by live steam from the boiler instead of exhaust steam, and by referring to the tabulated results of tests it will be noted that the over-all thermal efficiency of test No. 4 is only 43.7 per cent while that of tests Nos. 1, 2, and 3 is 69.1, 60.6, and 69.7 per cent, respectively, although the thermal efficiency of the heater in test No. 4 was the greatest.

The over-all efficiency is here taken as the ratio of the heat supplied by the boiler to the steam to that absorbed by the cream.

The thermal efficiency of the heater is the ratio of the available heat in the steam supplied to the heater to that absorbed by the cream.

HEAT BALANCE.

No heat balance is given in Table 2 because the pasteurizing equipments in tests Nos. 1, 2, and 3 were installed in market cream plants, that is, plants whose business consisted in the handling and marketing of cream. The cream as received from auxiliary creameries was first run through separators, the result being a heavy cream containing about 40 per cent fat. This heavy cream on the way to the coolers was mixed with skimmed milk in the correct proportion to produce a cream containing a predetermined amount of fat. In view of the methods employed in these plants, it was impractical to get out a heat balance showing the distribution of heat in the pasteurizing cycle.

TABLE 2.—Results of tests of four cream-pasteurizing plants.

	Plant No.			
	1	2	3	4
Time of operation.....hours.....	3.53	1.733	1.5	1.166
Amount of cream pasteurized.....pounds.....	50,683	6,928	5,019.5	4,571
Amount of steam used in the pasteurizer.....do.....	5,589.5	1,088	647.5	529
Heat supplied by boiler to steam, 80 pounds pressure, B. t. u.....	6,437,646	1,253,478	746,003	617,113
Heat in steam required to drive pasteurizing equipment, B. t. u.....	5,589,500	1,088,000	647,500	529,000
Heat supplied to pasteurizer.....do.....				
Total boiler horsepower developed for pasteurizing, B. H. P.....	193.2	37.6	22.4	29.9
Boiler horsepower per hour developed for pasteurizing, B. H. P.....	54.7	21.7	14.9	25.6
Total heater horsepower consumed for pasteurizing, do.....	167.7	32.6	19.4	15.9
Heater horsepower per hour consumed for pasteurizing, B. H. P.....	47.5	18.8	13.0	13.6
Cream pasteurized per boiler horsepower.....pounds.....	262	184	224	153
Cream pasteurized per heater horsepower.....do.....	302	212	258	287
Coal burned in pasteurizing.....do.....	1,030	200	119	160
Cream pasteurized per pound of coal.....do.....	49.2	34.6	42.2	29.0
Total B. t. u. absorbed by cream.....B. t. u.....	4,447,433	760,030	520,171	436,176
The over-all thermal efficiency of pasteurizing equip- ment.....per cent.....	69.1	60.6	69.7	43.7
Thermal efficiency of heater.....do.....	79.4	69.8	80.3	82.5

TABLE 2.—*Results of tests of four cream-pasteurizing plants—Continued.*

COOLING.

	Plant No.			
	1	2	3	4
Cooling water used in water section of cooler...cubic feet..	1,877	704	169	148
Ice used in cooling cream to its original temperature, tons.....	3.44	.92	.83	1.72

COSTS.

Capital invested in pasteurizing equipment (pasteurizer, vats, coolers, etc.).....	\$7,400.00	\$1,255.00	\$600.00	\$700.00
Interest per day on investment at 6 per cent per annum.....	1.233	.206	.098	.115
Repairs and depreciation per day at 25 per cent per annum.....	5.068	.586	.411	.489
Capital invested in mechanical equipment used for pasteurizing (engine, boiler, shafting, etc.).....	1,350.00	1,000.00	500.00	800.00
Interest on investment per day at 6 per cent per annum.....	.222	.164	.082	.131
Repairs and depreciation per day at 10 per cent per annum.....	.370	.274	.137	.219
Labor for pasteurizing.....	10.000	2.000	2.000	2.000
Cost of coal at \$4 per ton (2,240 pounds).....	1.839	.357	.203	.285
Cost of cooling water at 50 cents per 1,000 cubic feet.....	.938	.352	.084	.074
Cost of refrigeration at \$1 per ton.....	3.440	.920	.830	1.720
Cost of pasteurizing daily supply of cream.....	23.110	4.857	3.845	5.033
Cost of pasteurizing 1 gallon of cream.....	.00378	.00582	.00636	.00639
Cost of pasteurizing 100 pounds of cream.....	.0456	.0701	.0765	.1101
Average cost of pasteurizing 1 gallon of cream in the four tests.....	.00634			
Average cost of pasteurizing 100 pounds of cream in the four tests.....	.0756			

TEMPERATURE BALANCE.

	1	2	3 ¹	4 ²
Temperature of raw milk.....°F..	49.5	42.0	39.3	56.25
Temperature of milk in heater.....°F..	147.0	169.6	160.2	167.25
Rise of temperature in heater.....°F..	97.5	127.6	120.9	111.00
Total per cent rise.....per cent..	100	100	100	100
Temperature of milk in holder.....°F..	147.0	169.6		
Drop of temperature in holder.....°F..	3.0	³ 16.8		
Per cent drop in holder.....per cent..	3.1	³ 13.2		
Temperature of milk in separator.....°F..	144.0	152.8	160.2	
Drop of temperature in separator (milk).....°F..	9.2	7.2	1.8	
Per cent drop in separator (milk).....per cent..	9.4	5.6	1.5	
Drop of temperature in separator (cream).....°F..	12.8	15.3	5.0	
Per cent drop in separator (cream).....per cent..	13.2	12.0	4.1	
Temperature of milk in cooler.....°F..	134.8	145.6	153.4	
Drop of temperature in cooler (milk).....°F..	85.3	103.6	119.1	
Per cent drop in cooler (milk).....per cent..	87.5	81.2	98.5	
Temperature of cream in cooler.....°F..	131.2	137.5	155.2	167.25
Drop of temperature in cooler (cream).....°F..	81.7	95.5	115.9	111.00
Per cent drop in cooler (cream).....per cent..	83.7	74.8	95.9	
Total per cent drop.....do.....	100	100	100	100

¹ No holder.³ Large drop in holder was due to stirring apparatus.² No holder or separator.

The summary of the tests in Table 2 gives the cost of pasteurizing at the different plants under the conditions at which each particular plant was operating at the time of the test. Therefore the cost of pasteurizing 100 pounds of cream will vary slightly in the different plants due to the varying conditions. It will be noted from an inspection of the temperature balance that the initial temperature of the raw cream varied in the different plants and also the final or pasteurizing temperatures. In order to make a comparison of cost

it becomes necessary to put them all on an equal basis, so far as it is possible to do so, and for this purpose it is assumed that the pasteurizing cycle consisted in raising and lowering the temperature of the cream through a range of 100° F., all other conditions remaining the same. The cost of pasteurizing 100 pounds of cream in the different plants, corrected as above, is \$0.0459, \$0.0650, \$0.0726, and \$0.1056 for tests Nos. 1, 2, 3, and 4, respectively.

The amount of cream handled will, of course, affect the unit cost to a great extent, as may be gathered from the summary of tests.

Referring to test No. 4, the power required for driving the pasteurizing equipment was excessive, as a considerable amount of line shafting was uselessly driven while pasteurizing. This, together with taking steam from the boiler through a reducing valve instead of using the heat from the exhaust steam, accounts for the high cost of pasteurizing at this plant.

CONCLUSIONS.

The conclusions drawn from the foregoing tests are as follows:

1. The flash process of pasteurization requires approximately 17 per cent more heat than the holder process. There is a correspondingly wider range through which the milk or cream must be cooled, both adding extra cost to the pasteurizing cycle.

2. The proper design and arrangement of the heater, regenerator, cooler, piping, and refrigerating apparatus have much to do with the efficient operation of the plant.

3. With poorly arranged apparatus and leaky piping the loss in heat may reach approximately 30 per cent of that required to pasteurize, which it is practicable to reduce to a negligible amount.

4. It is practicable to use exhaust steam from the engine and steam-driven auxiliaries, or water heated by exhaust steam, to furnish heat with which to pasteurize both milk and cream.

5. Usually there is sufficient heat in the exhaust steam which is allowed to waste in milk plants and creameries to do the pasteurizing.

6. For every 400 pounds of milk pasteurized per hour with exhaust steam, approximately one horsepower is taken off the boiler plant.

7. The average cost of pasteurizing 1 gallon of milk is shown to be \$0.00313.

8. The average cost of pasteurizing 1 gallon of cream is shown to be \$0.00634, or \$0.0756 per 100 pounds.

9. It must be understood that the cost of pasteurizing as figured in this paper deals only with the pasteurizing cycle, viz, starting with the initial temperature of the raw milk and raising its temperature to the pasteurizing point, then cooling the milk down to the initial temperature of the raw milk. In other words, it has been attempted to show the additional expense encountered in producing pasteurized milk and cream over the raw product.



BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE



No. 86

Contribution from the Forest Products Laboratory, Forest Service,
Henry S. Graves, Forester.
March 14, 1914.

(PROFESSIONAL PAPER.)

TESTS OF WOODEN BARRELS.

By J. A. NEWLIN,
Engineer in Charge of Timber Tests.

OBJECT OF THE TESTS.

The object of the tests described in this bulletin, made in cooperation with the Bureau for the Safe Transportation of Dangerous Explosives, was to obtain data upon which specifications and changes in the design of wooden barrels used in the transportation of dangerous liquids might be based. The tests do not offer any comparisons between barrels made of different material or of different species of timber.

MATERIAL.

The barrels used in the test were made by the St. Louis Cooperage Co., and were received in six groups of 8 barrels each (48 in all) as follows:

Group No.	Barrel No.	Thickness of staves and heads.	Number of hoops.
1	1 to 8	<i>Inches.</i>	6
2	1a to 8a	$\frac{5}{8}$	8
3	9 to 16	$\frac{3}{4}$	6
4	9a to 16a	$\frac{3}{4}$	8
5	17 to 24	$\frac{7}{8}$	6
6	17a to 24a	$\frac{7}{8}$	8

The barrels were made from quarter-sawed white oak. (One stave which seemed to be particularly porous was identified as red oak.) The material was practically straight grained and free from defects. The barrels were of excellent workmanship and were well coated with paraffin on the inside. The staves varied in width from about $2\frac{1}{2}$ inches to about 7 inches. Thirty-one barrels had 19 staves each, 12 had 20 each, and 4 had 21 each. The heads were usually

NOTE.—This bulletin describes tests that are of special interest to barrel manufacturers and to manufacturers and shippers of dangerous liquids.

composed of four pieces, though two heads were each composed of three pieces. The pieces of the head were joined together with $\frac{5}{16}$ -inch hickory dowels. There were two dowels per joint, each about one-third or one-fourth the length of the joint from its end.

The head and bilge hoops were $1\frac{3}{4}$ inches by 17 gauge, while the quarter hoops were $1\frac{1}{2}$ inches by 18 gauge. The average thicknesses of hoops used for tension tests (see p. 4) were 0.051 inch and 0.061 inch for the 18 and 17 gauge, respectively, while the U. S. standard gauges of these numbers are 0.05 inch and 0.05625 inch.

The average hoop spacing, dimensions, weights, and capacities of the barrels are shown on figure 1. The hoop splices were always placed over the bung stave, and the heads were placed with their end grain toward this stave as shown in I and II, figure 1.

The barrels were received at the laboratory on November 24, and were stored in a closed and unheated shed until the tests were begun on December 10.

BARREL TESTS.

The barrels were brought in from the storage shed shortly before the time for test. Each barrel was then carefully inspected and the hoops driven tight by a representative of the St. Louis Cooperage Co. Just before test each barrel was completely filled with water, and with the exception of those barrels to which a pressure gauge was attached, was closed with a wooden bung. These bungs, after soaking for a few seconds in warm water, were driven to a tight fit. They were placed with their grain parallel to that of the staves. The bungs bore the brand "U. S. Bung Mfg. Co., Cincinnati, O." No bung straps were used.

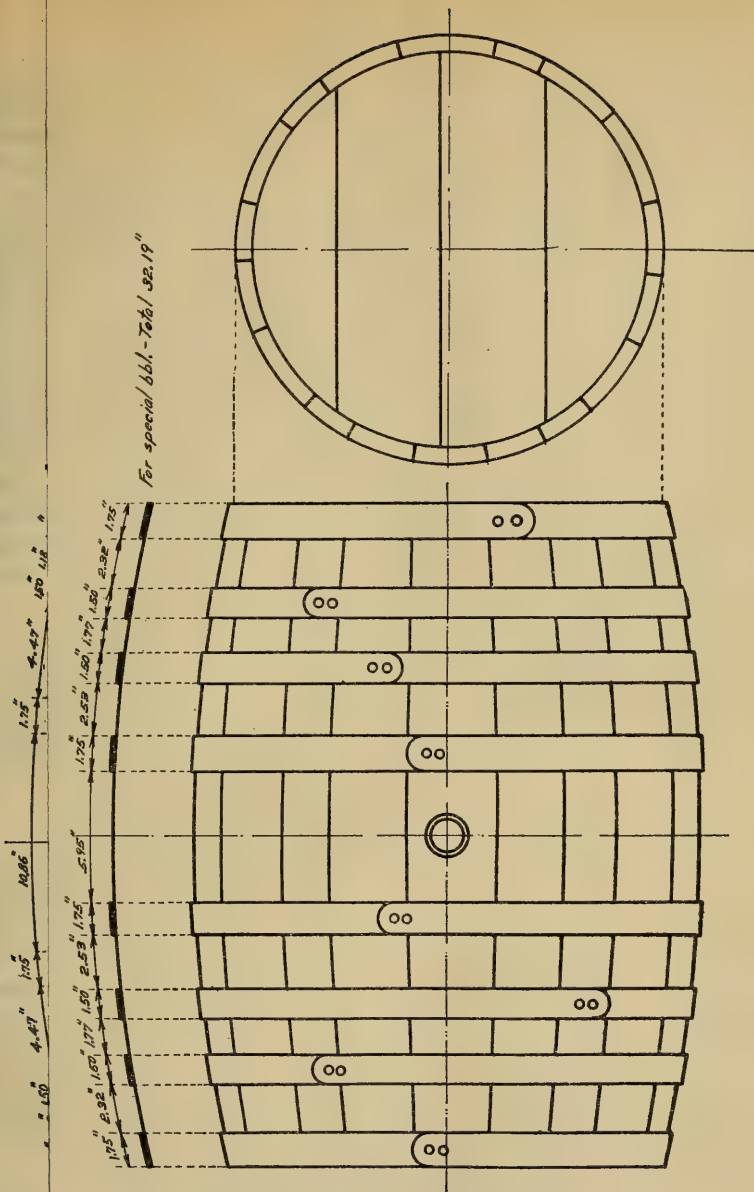
Two barrels of each group were tested in side compression, two in diagonal compression, one each in side and diagonal drop, and two by internal pressure.

SIDE-COMPRESSION TESTS.

In this test the barrel was placed between two flat surfaces and compressed in the direction of its diameter. The rate of compression was 0.25 inch per minute. Simultaneous readings of load, compression, and loss of water from the barrel were taken. The test was discontinued when one-half the water had escaped. Notes were made of the character and sequence of failures. In about one-half of these tests a pressure gauge was attached to the barrel, and readings of internal pressure were taken. The method of test is shown in Plate I.

DIAGONAL-COMPRESSION TEST.

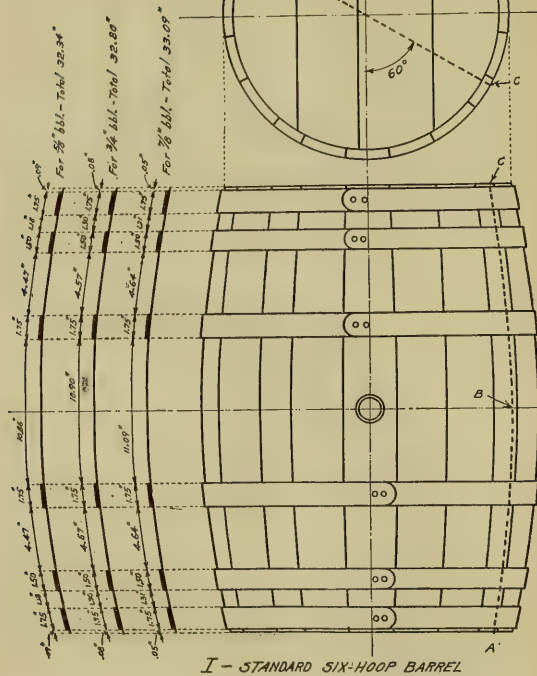
In this test the barrel was compressed between two flat surfaces, being supported upon one point of the chime and loaded at a point on the other and diagonally opposite. The rate of compression was 0.25 inch per minute. Notes were taken as in the side compression test. The test on the first barrel of each group was discontinued as



III - MADEUP BARREL-EIGHT HOOPS
5/8" STAVES 7/8" HEAD

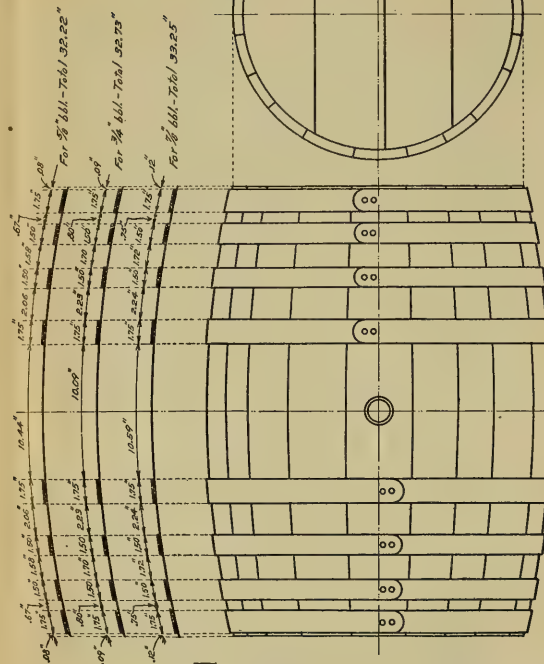
Weight Pounds	Capacity	
	Pounds	Gallons
68.9	424.1	50.8

and diagonal-drop tests "C" was the top point. Outside diameters of all 24.9 inches; average diameter at the head was 21.2 inches.



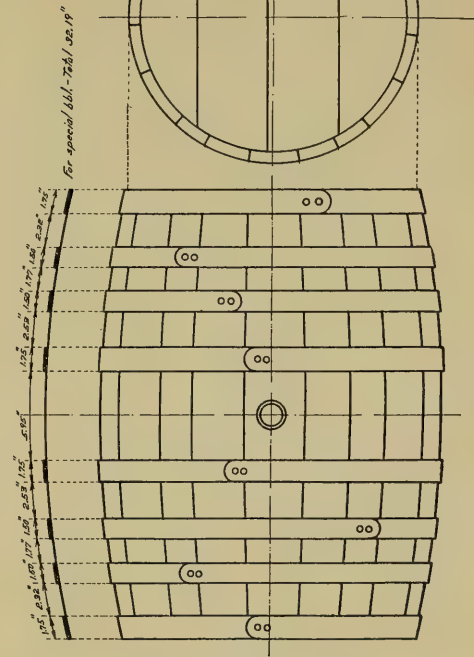
I - STANDARD SIX-HOOP BARREL

Thickness Inches	Weight Pounds	Capacity	
		Pounds	Gallons
5/8	64.8	427.2	51.2
3/4	71.0	421.5	50.5
7/8	79.2	417.9	50.1



II - STANDARD EIGHT-HOOP BARREL

Thickness Inches	Weight Pounds	Capacity	
		Pounds	Gallons
5/8	67.4	426.7	51.2
3/4	74.6	420.4	50.4
7/8	82.6	417.3	50.0



III - MADEUP BARREL - EIGHT HOOPS
5/8" STAVES 5/8" HEAD

Weight Pounds	Capacity	
	Pounds	Gallons
68.9	424.1	50.8

FIG. 1.—In the compression and drop tests all barrels were placed with plane A B C D (I) vertical. In the side-compression and side-drop tests 'B' was the top point. In the diagonal-compression and diagonal-drop tests 'C' was the top point. Outside diameters of all regular barrels were practically the same, the total variations being about one-third inch in bung diameter and about one-tenth inch in diameter at the head. Average bung diameter was 24.9 inches; average diameter at the head was 21.2 inches.

in the preceding test, while the second was discontinued whenever one-half the contents had escaped or would have escaped had the barrel been in the reverse position. This test is illustrated in Plate II.

SIDE-DROP TEST.

In this test the barrels were dropped on a wooden platform about $3\frac{1}{2}$ inches thick resting on the concrete floor of the laboratory. On top of this platform was a steel plate one-eighth inch in thickness. The barrel was suspended with its axis horizontal. The first drop was 3 inches, the next 6 inches, etc., increasing each time by 3 inches. Each drop was upon the same point of the barrel. After the first apparent leak the drops were made at 3-minute intervals. The weight of the barrel and contents was taken immediately before each drop. The test was continued until half the contents of the barrel had escaped. Complete notes were made to show the character and sequence of the failures. A picture of this test is shown in Plate III.

DIAGONAL-DROP TEST.

This test was conducted in the manner described for the side-drop test, except that the barrel was suspended so that the lowest point of the chime was directly below the center of the barrel, which was dropped on the chime. Each drop was upon the same point. A picture of this test is shown in Plate IV.

INTERNAL-PRESSURE TEST.

In this test the barrel and connecting pipes were filled with water in such a way as to exclude as nearly as possible all air. The pressure was then raised to 2 pounds per square inch and held for 2 minutes. It was then raised to 4 pounds and there held for 2 minutes. This was repeated, increasing the pressure 2 pounds each time and holding it constant for 2 minutes after each increase, until 1 pound of water ran from the barrel in 1 minute or less. The test was then discontinued. Complete notes were made as to the character and sequence of the failures.

In these tests connection to the barrel was made by screwing a special tapered bush into the bung-hole. The apparatus is shown in Plate V.

MINOR TESTS.

STAVE TESTS.

In order to find out something of the variability of the barrel material tests were made on 36 staves, two from each of 6 barrels of each thickness. The best and poorest appearing stave of each barrel was chosen. Pieces 2 inches in width, cut from these staves, were tested in static bending under center loading. The span was 28 inches. The staves were placed with the outer side up.

HOOP TESTS.

A 14-inch piece was taken from one hoop of each gauge from each of three barrels of each group. These pieces were machined down to have a parallel section approximately 1 inch by 9 inches, and were then subjected to tension tests. The maximum load and load at yield point, as determined from the drop of the scale beam of the testing machine, were recorded.

RESULTS.

BARREL TESTS.

The results of the barrel tests are given in Tables 3 to 6, inclusive.

The internal-pressure readings on the barrels to which a pressure gauge was attached in the side-compression test have been omitted. The highest internal pressure developed in these barrels was 7 pounds per square inch.

In all the test only two or three cases of leakage at the bung was observed. These also have been omitted from the tabulated results.

MINOR TESTS.

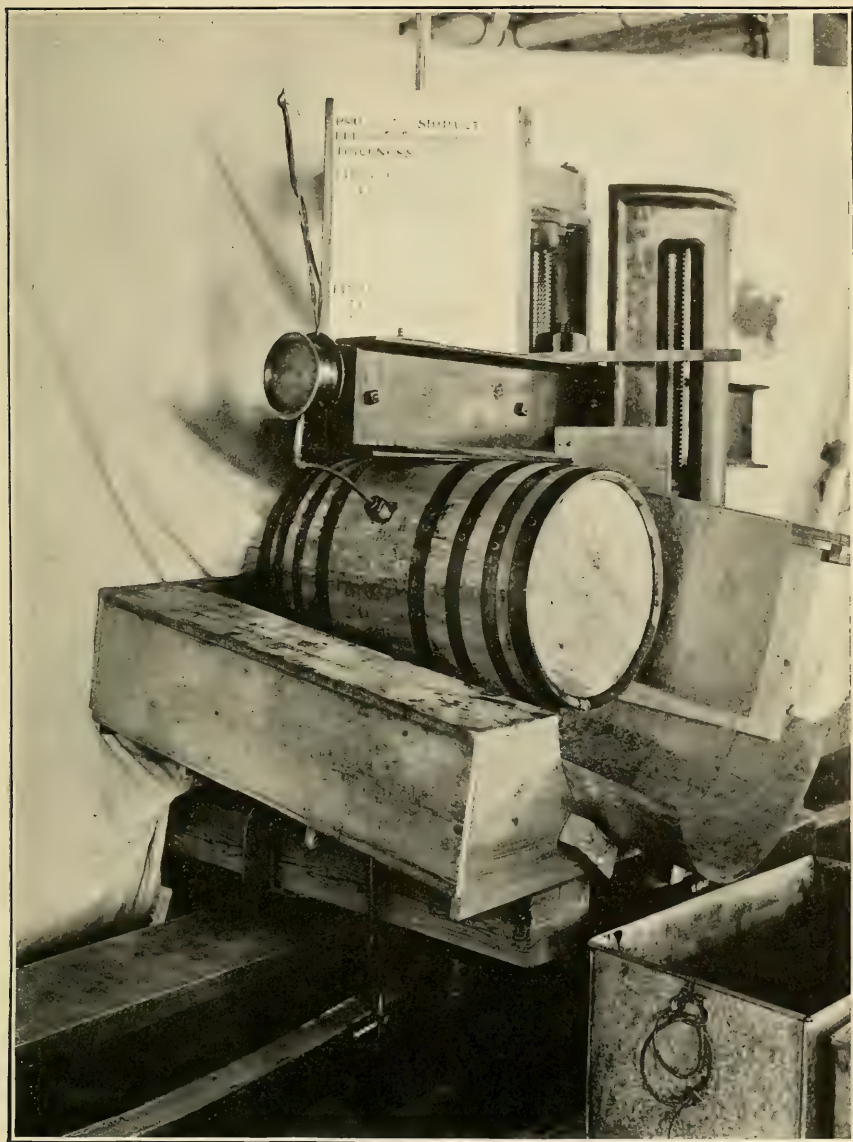
The average, maximum, and minimum results of the stave and hoop tests are given in Tables 1 and 2. In Table 1 "modulus of rupture" is the fiber stress at maximum load and represents the strength of the timber. "Work to maximum load" is proportional to the shock-resisting ability of the timber.

TABLE 1.—Results of stave tests. Static bending, 28-inch span.

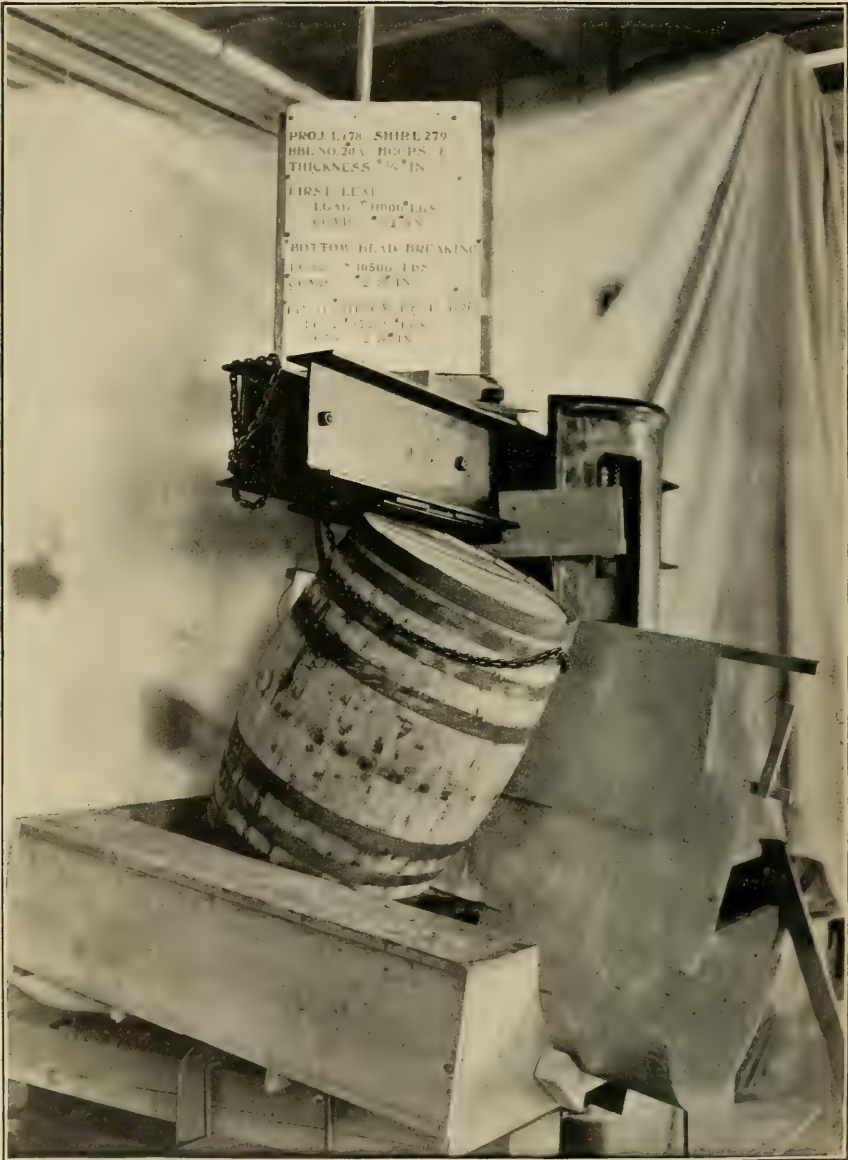
	½-inch staves.			¾-inch staves.			1-inch staves.		
	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
Measured thickness at stave, inches.....	0.69	0.71	0.65	0.77	0.80	0.74	0.89	0.91	0.87
Rings.....per inch.....	15	29	8	14	25	8	21	30	14
Specific gravity.....per inch.....	0.672	0.848	0.528	0.694	0.820	0.558	0.663	0.723	0.544
Moisture.....per cent.....	10.4	14.1	8.1	9.8	13.5	7.3	12.6	14.8	10.0
Maximum load.....pounds.....	257	395	100	378	490	220	387	510	240
Deflection at maximum load, inches.....	2.31	5.20	0.88	1.98	3.50	1.22	1.90	3.50	1.10
Modulus of rupture, pounds per square inch.....	11,455	17,950	4,290	13,260	17,460	8,220	10,120	12,860	6,330
Work to maximum load, inch-pounds per cubic inch.....	10.2	29.8	1.4	10.0	17.2	3.8	10.0	16.7	3.8

TABLE 2.—Results of hoop tests. Tension, specimens 1 inch wide.

	18-gauge hoops.			17-gauge hoops.		
	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
Measured thickness of hoops, inches.....	0.051	0.058	0.047	0.061	0.063	0.058
Load at yield point as determined by drop of beam.....pounds.....	2,360	2,900	2,100	2,480	2,620	2,330
Maximum load.....do.....	3,955	4,530	3,580	4,925	5,130	4,605
Fiber stress at yield point, pounds per square inch.....	44,580	49,500	41,200	39,515	42,400	36,000
Fiber stress at maximum load, pounds per square inch.....	74,210	78,600	70,200	78,060	82,400	71,600



METHOD OF TEST—SIDE COMPRESSION.



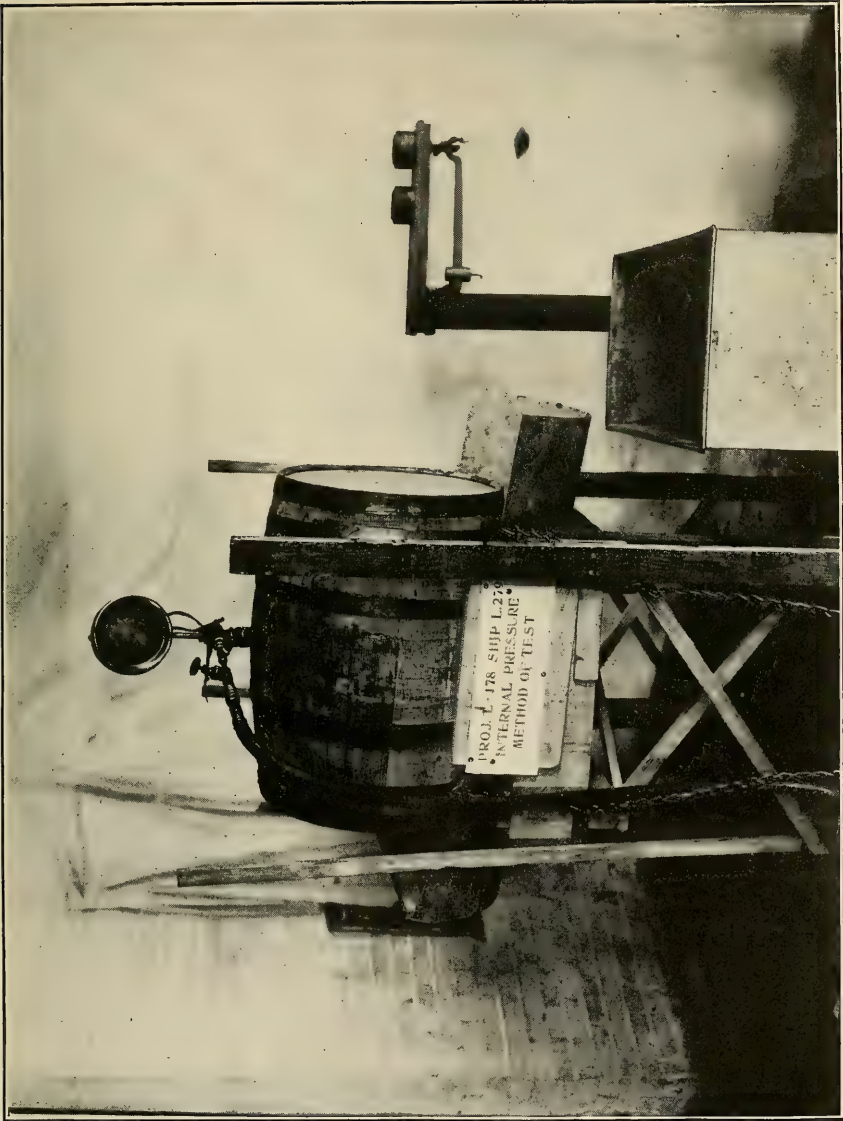
METHOD OF TEST—DIAGONAL COMPRESSION.



METHOD OF TEST—SIDE DROP.



METHOD OF TEST—DIAGONAL DROP.



METHOD OF TEST—INTERNAL PRESSURE.

GENERAL OBSERVATIONS OF NATURE OF FAILURES.

In each kind of test the first water to appear on the outside of the barrel was usually from the seepage through the pores of the wood at the chime. The first leak usually occurred either between the staves and the head or between the staves at the chime. In all the tests except the internal pressure the first leak was usually coincident with the slipping of the staves.

In the internal-pressure test there were two general classes of failures: (1) By springing and breaking of the head; and (2) by leaking between the staves at the bilge.

In the diagonal-compression test the failure was a general failure of the head combined with the slipping of the staves. In the compression-perpendicular test the failure was a general leaking at the heads and slipping of the staves followed by the breaking of the staves at the bilge.

In the side-drop test the slipping of the staves caused loosening of the hoops and leakage at the heads. This was followed by breaking of the staves at the bilge. In three of the six tests the failure of the barrels was due to the heads being broken or forced out by the internal pressure produced by the impact.

The lower heads of all barrels tested by dropping on the chime were broken or forced out by the pressure due to the impact.

CHANGES IN DESIGN AS INDICATED BY THE CHARACTER OF THE FAILURES.

A slight increase in the length of the chime from croze to the end of the stave would lessen the amount of seepage without any marked increase of liability to breakage at the croze by dropping the barrel on the chime. The chimes of the test barrels were made exceptionally short (three-fourths of an inch from outer side of croze to end of stave) to reduce the danger of breakage when dropped on the chime. Chimes 1 inch long would probably have given better results.

The internal-pressure test and the side-drop test indicated that the bilge hoops were too wide apart. A spacing of not more than 8 inches between the bilge hoops would have materially strengthened the barrels for the internal pressure without any weakening for the other tests.

The weakest parts of the barrels were the heads. The first leak in most of the tests was due either to the springing of the head or to the slipping of the staves at the head, or to both these causes.

The ultimate failure of a large per cent of the barrels was at the head. It appears that a head much thicker than the staves would give materially better results. Heads should probably be made about one and one-half times as thick as the staves.

The heads appeared to be materially weakened by the dowel holes and not infrequently the flagging was forced out. It would seem that these head joints could be improved.

None of the hoops failed during the test. A $\frac{7}{8}$ -inch oak barrel should probably have not less than eight hoops of the sizes of those used on the barrels tested, as the swelling of the wood might break the hoops.

Variation in strength of barrels of the same design is due in large measure to the variability of the wood composing the head and staves. Test specimens taken from these barrels show that some of the staves may have less than one-fourth the strength of others. (See Table 1, p. 4.) Evidently no attempt had been made to grade the staves on the basis of strength, the only criterion of fitness being that the staves should be clear and straight grained. The dry weight per cubic foot of clear straight-grained wood is a splendid guide as to probable strength, the heavier, denser wood being the stronger. The advisability of grading staves and heading with reference to the strength might well be considered.

TESTS OF MADE-UP BARRELS.

BARRELS.

In order to try out the effect of some of the changes in design as suggested above, barrels were made up with $\frac{5}{8}$ -inch staves, $\frac{7}{8}$ -inch head, and eight hoops. The staves and hoops were from the two 8-hoop, $\frac{5}{8}$ -inch barrels, the heads from $\frac{7}{8}$ -inch barrels and previously tested under internal pressure. In order to make these heads fit, it was necessary to joint fifteen-sixteenths inch off of one stave of each barrel. The bilge and quarter hoops were not changed, but were permitted to drive farther onto the barrels. The head hoops were shortened $1\frac{1}{2}$ inches and were driven flush with the ends of the staves. (In the original tests the head hoops were driven beyond the ends of the staves, as shown in I and II of fig. 1.) The spacing of the hoops, weight, capacity, etc., of these barrels are shown in III, figure 1. In assembling the barrels the hoop joints were placed at random.

INTERNAL-PRESSURE TESTS.

The two made-up barrels were tested under internal pressure. The results of these tests showed them to be fully equal to the barrels with $\frac{7}{8}$ -inch heads and staves. One of these barrels withstood a pressure of 34 pounds per square inch up to the time the head began to fail, when the pressure was released. The increased capacity of the barrel under this pressure, due primarily to the springing of the heads, was $8\frac{1}{4}$ pounds of water. On release of the pressure the barrel resumed its original form with no apparent leakage.

The head of the second barrel was broken out by a pressure of 38 pounds per square inch.

Neither of these made-up barrels showed any leakage between the staves during the tests.

DROP TESTS.

The broken heads of the made-up barrels were replaced by other $\frac{7}{8}$ -inch heads, and the barrels subjected to drop tests. The barrel dropped upon the side showed much better resistance than the 8-hoop barrel five-eighths inch in thickness throughout, but was not quite the equal of the $\frac{7}{8}$ -inch barrels.

In dropping on the chime the made-up barrel was the equal of any barrel tested.

These tests of made-up barrels seem to justify the previously suggested changes in thickness of head and spacing of hoops.

The detailed results of these tests are given in Table 5.

SUGGESTIONS REGARDING TESTS OF SHIPPING CONTAINERS.

There are two classes of tests to which containers such as barrels may be subjected:

First. Tests, such as the ones described in this bulletin, where the object is to determine the most economical and efficient designs. Tests of this class are usually carried to the destruction of the container and entail damage or complete loss of contents. It is necessary to fill the containers with material which is relatively inexpensive, safe to the investigators, and which will produce stresses similar in character to those which would be produced by the commodity which the container is intended to carry.

Second. Tests to determine the suitability of the container for specified commodities under practical conditions. Such tests should be made upon containers filled with the material to be shipped in them or with some other very similar in its action on the container.

In the case of the first class of tests seepage through the pores and the first leak depend largely upon the nature of the lining and of the contained liquid. A material difference might be expected in the behavior of barrels lined with paraffin and filled with water as compared with barrels lined with glue and filled with gasoline. In the drop test the height of drop also depends upon the specific gravity of the contained liquid. The height of drop required to produce given stresses is in approximately inverse proportion to the combined weight of barrel and contents.

Having made tests of the first class, and so determined the best construction, it then remains to manufacture containers in accordance with specifications based upon the results of these tests. Tests of the second class made upon such containers lined according to commercial practice and filled with the commodity they are to carry would show their limitations under practical conditions.

In the case of barrels internal-pressure and side-drop tests are recommended for this purpose.

TABLE 3.—*Individual tests—Side compression.* $\frac{3}{4}$ -INCH BARRELS.

No. of barrel.	Number of hoops.	Deflection.	Load.	Rate of leaking.	Remarks.
				<i>Lbs. per minute.</i>	
1	6	0.81	5,000	-----	Seepage through pores.
		1.12	6,000	-----	Staves slip.
		1.24	6,340	-----	Leak between staves.
		2.35	8,920	-----	Stave broke.
		3.80	11,000	1.6	Horizontal shear in top stave.
		5.38	14,380	6.5	Stave broke.
2	6	6.35	13,640	42.8	One-half contents escaped.
		.88	5,000	-----	Leak at chime.
		1.20	6,000	-----	Stave slipped.
		2.54	8,500	1.7	Stave sheared.
1a	8	5.97	10,850	29.0	One-half contents escaped.
		.85	5,500	-----	Leak between staves.
		1.08	6,500	-----	Staves slip.
		2.80	9,460	2.1	Bottom stave sheared.
2a	8	3.80	11,250	15.0	Stave split.
		4.37	11,000	23.0	Stave broke.
		5.40	12,310	31.0	Do.
		5.70	11,880	32.0	One-half contents escaped.
		.60	4,500	-----	Seepage through pores.
		.64	4,750	-----	Leakage around end at bottom.
		1.55	7,500	-----	Staves slip.
		3.80	12,320	2.9	Stave broke.
		4.62	12,070	2.0	Bottom stave broke.
		7.11	15,040	28.0	Stave broke.
		7.61	15,370	52.0	One-half contents escaped.

 $\frac{3}{4}$ -INCH BARRELS.

9	6	0.57	5,000	-----	Leak at chime.
		.77	6,000	-----	Seepage through pores.
		.86	6,500	-----	Staves slip.
		2.35	9,730	10.5	Stave broke.
		3.36	10,830	37.0	Do.
10	6	3.75	11,380	39.4	One-half contents escaped.
		.77	5,500	-----	Seepage through pores.
		.90	6,000	-----	Staves slip.
		1.24	7,000	-----	Leak between staves and at chimes.
		2.88	10,910	9.0	Bottom stave broke.
9a	8	4.00	11,110	39.0	Increased breaking.
		4.30	10,420	57.0	One-half contents escaped.
		.64	5,500	-----	Leak between staves.
		.86	6,500	-----	Leak at chime.
		1.15	8,000	-----	Staves slip.
10a	8	3.60	11,590	25.2	Top stave sheared.
		4.35	12,430	37.5	Bottom stave broke.
		4.53	12,390	33.6	One-half contents escaped.
		.57	5,000	-----	Leak at chime.
		1.03	7,000	-----	Staves slip.
		1.70	8,860	1.0	Leak between staves.
		3.80	12,010	34.0	One-half contents escaped.

 $\frac{7}{8}$ -INCH BARRELS.

17	6	0.86	5,500	-----	Leak at chime.
		1.20	6,500	-----	Staves slip.
		4.27	12,870	21.3	Top stave broke.
		4.40	12,260	24.8	Do.
		4.91	11,110	28.0	Stave broke.
18	6	5.58	11,830	35.2	One-half contents escaped.
		.90	6,500	-----	Leak through joint of head.
		1.10	7,000	-----	Seepage through pores.
		1.63	8,500	-----	Leak between staves.
		2.14	9,000	1.5	Stave broke.
17a	8	5.78	12,940	26.8	One-half contents escaped.
		.56	4,500	-----	Leak at chime.
		.92	6,000	-----	Seepage through pores.
		1.22	7,000	-----	Staves slip.
		2.75	10,750	5.1	Head coming loose.
18a	8	3.75	12,150	23.1	Top stave broke.
		4.15	12,200	35.4	Do.
		4.65	12,530	34.0	Stave broke.
		4.88	13,020	40.0	One-half contents escaped.
		.83	6,000	-----	Leak at chime; staves slip.
		1.00	6,500	-----	Leak between staves.
		2.95	11,100	1.0	Top stave broke.
		5.43	16,280	20.0	Bottom stave broke.
		5.50	15,190	20.0	Do.
		6.40	14,090	40.5	One-half contents escaped.

TABLE 4.—*Individual tests—Diagonal compression.* $\frac{3}{8}$ -INCH BARRELS.

No. of barrel.	Number of hoops.	Deflection.	Load.	Rate of leaking.	Remarks.
				<i>Lbs. per minute.</i>	
3	6	0.56	7,000	-----	Leak at chime.
		1.45	11,000	-----	Staves sheared.
		3.40	15,620	-----	Bottom head broke.
		3.56	10,020	-----	One-half contents escaped.
4	6	.77	8,000	-----	Leak at chime; staves slipping.
		3.78	16,240	-----	Bottom head broke.
		4.48	16,990	-----	One-half contents escaped.
		.85	8,500	-----	Leak at bottom chime.
3a	8	1.38	13,000	-----	Leak at top chime.
		1.55	14,000	-----	Staves slipping.
		2.26	16,400	-----	Top head breaking.
		2.85	15,000	-----	Top head broke.
4a	8	.97	8,500	-----	Leaks at top and bottom chimes.
		1.73	14,480	-----	Staves slip; bottom head breaking.
		2.50	15,440	-----	Bottom head broke.
				14.5	

 $\frac{3}{8}$ -INCH BARRELS.

11	6	0.62	7,500	-----	Leak at chime.
		1.18	11,000	-----	Leak at bearing.
		1.50	12,460	-----	Top head broke; staves sheared.
		5.73	17,000	-----	Staves breaking at top.
12	6	8.42	17,850	-----	One-half contents escaped.
		.90	9,000	-----	Leak at bottom stave.
		1.26	11,500	-----	Stave splitting at top.
		1.50	12,500	-----	Leak at bottom chime.
11a	8	3.20	16,530	-----	Bottom head broke.
		.58	8,000	-----	Leak at bottom chime.
		1.48	14,500	-----	Staves slipping.
		2.10	16,000	-----	Top head broke.
12a	8	.75	8,000	-----	Leak at top chime.
		1.53	14,000	-----	Staves slipping.
		2.47	16,970	-----	Top head broke.
		9.25	24,260	-----	Test discontinued.

 $\frac{3}{8}$ -INCH BARRELS.

19	6	0.42	6,500	-----	Leak at bottom chime.
		.77	8,500	-----	Staves slipping.
		1.68	11,500	-----	Leak at top chime.
		3.73	17,660	-----	Top head splitting.
20	6	5.50	18,000	-----	Top head broke.
		7.47	11,540	-----	One-half contents escaped.
		.81	9,500	-----	Leak at bottom chime; staves slipping.
		1.12	10,500	-----	Leak between staves at bottom.
19a	8	2.34	14,560	-----	Staves slipping.
		4.20	19,280	-----	Top head breaking.
		5.00	20,530	-----	Top head broke.
		.62	8,000	-----	Leak at bottom chime.
20a	8	1.43	13,000	-----	Staves slipping.
		3.83	19,790	-----	Staves sheared at chime.
		4.85	21,740	-----	Top head broke.
		5.05	21,650	-----	One-half contents escaped.
		.82	11,000	-----	Leak at bottom chime.
		.95	11,500	-----	Staves slipping.
		1.27	12,500	-----	Leak at top chime.
		2.35	16,500	-----	Bottom head breaking.
		2.70	17,200	-----	Bottom head broke.

TABLE 5.—*Individual tests—Drop tests.* $\frac{3}{8}$ -INCH BARRELS.

No. of barrel.	Number of hoops.	Height of drop.	Rate of leakage.	Remarks.
SIDE DROP.				
5	6	<i>Inches.</i> 6	<i>Lbs. per minute.</i> -----	Stave slipped; leak at chimes.
		12	-----	Leak between staves.
		18	0.3	Stave cracked.
		24	.7	Head cracked; hoops slipped at head.
5a	8	30	2.0	Head broke out.
		6	-----	Leak at chime and between staves.
		9	-----	Staves slipping.
		12	-----	Stave broke.
		24	.3	Flag coming out at head.
		27	2.0	Head broke out; split at dowels.
DIAGONAL DROP.				
6	6	9	-----	Leak at chime.
6a	8	12	-----	Head broke.
		9	-----	Head broke out.

 $\frac{1}{2}$ -INCH BARRELS.

SIDE DROP.				
13	6	6	-----	Leaking slightly.
		9	-----	Leak of chime and between staves.
		15	0.2	Stave broke.
		24	1.0	Hoop slipped at head.
13a	8	39	23.2	Test discontinued.
		9	-----	Leak at chime; stave slipped.
		12	-----	Stave broke.
		21	35.7	Bilge hoop slipped.
DIAGONAL DROP.				
14	6	9	-----	Leak at chime.
		15	-----	Head failing.
		18	-----	Head broke out.
14a	8	9	-----	Leak between staves.
		15	-----	Flag coming out.
		18	0.3	Head broke out.

 $\frac{3}{4}$ -INCH BARRELS.

SIDE DROP.				
21	6	9	-----	Leaks at chimes; staves slipped.
		21	-----	Stave broke.
		24	-----	Bilge hoop slips.
		27	2.0	Head hoop slipped.
21a	8	48	11.3	Test discontinued.
		9	-----	Stave slips.
		21	-----	Leak at chime.
		33	.3	Head broke.
		36	.7	Head broke out.
DIAGONAL DROP.				
22	6	6	-----	Leak at chime.
		12	-----	Stave sheared.
		15	0.7	Leak through joint of head.
		21	.3	Head broke out.
22a	8	15	.6	Head breaking.
		18	.4	Head broke out.

TABLE 6.—*Individual tests—Internal pressure.* $\frac{3}{8}$ -INCH BARRELS.

No. of barrel.	Number of hoops.	Pressure.	Rate of leakage.			Remarks.
			<i>Lbs. per sq. inch.</i>	<i>Drops per minute.</i>	<i>Lbs. per minute.</i>	
7	6	2	.....	.....	.....	Seepage through pores.
		4	.....	5	.....	Leak between staves.
		8	.....	120	.....	Head bulged flush with chime.
		10	.....	.....	.....	Leak at chime; broken stream.
8	6	12	.....	.....	4	Leak between staves.
		2	.....	.....	.....	Leak at chime.
		4	.....	200	.....	.....
		6	.....	.....	.....	Leak between staves at bilge.
7a	8	8	.....	.....	.....	Heads bulged flush with chimes.
		10	.....	.....	.....	Seeping in stream through pores.
		12	.....	.....	.....	Leak through joints of head.
		13	.....	.....	.....	Displacement of flag.
8a	8	4	.....	.....	.....	Seepage through pores.
		8	.....	.....	.....	Leak at chimes and head bulged flush with chime.
		10	.....	120	.....	Leak through joints at end.
		16	.....	.....	.....	Flag forced out.
		2	.....	.....	.....	Seepage through pores.
		4	.....	.....	.....	Leak between staves at end.
		8	.....	.....	.....	Head bulged flush with chime; leak between staves at bilge and through joints in head.
		12	.....	60	.....	.....
		14	.....	.....	1.2	Leak in head.

 $\frac{3}{4}$ -INCH BARRELS.

15	6	2	.....	.....	.....	Seepage through pores.
		6	.....	.....	.....	Leak between staves at end.
		8	.....	108	.....	Streaming between staves at end.
		12	.....	120	.....	.....
16	6	14	.....	.....	.....	Head bulged flush with chime.
		16	.....	.....	2.0	Leak between staves at bilge.
		2	.....	.....	.....	Seepage through pores; leak at chime.
		4	.....	26	.....	.....
15a	8	10	.....	96	.....	.....
		14	.....	.....	.....	Leak between staves at bilge.
		16	.....	132	.....	Heads bulged flush with chime.
		18	.....	.....	.....	Leak between staves at quarter.
16a	8	22	.....	.....	2.0	General leak between staves.
		2	.....	.....	.....	Seepage through pores.
		4	.....	60	.....	Leak at chime.
		10	.....	.....	.....	Squirting at chime.
		12	.....	.....	.....	Leak between staves at end.
		14	.....	.....	.....	Head bulged flush with chime.
		18	.....	.....	2.4	Test discontinued.
		2	.....	.....	.....	Seepage through pores.
		4	.....	.....	.....	Leak at chime.
		8	.....	2	.....	.....
		10	.....	20	.....	.....
		14	.....	.....	.....	Leak between staves at bilge.
		16	.....	38	.....	Head bulged flush with chime.
		22	.....	.....	.....	Stream through joints of head.
		24	.....	.....	.....	Leak through joints of head; displaced flag.

 $\frac{7}{8}$ -INCH BARRELS.

23	6	4	.....	.....	.....	Leak at chime and at flag; seepage through pores.
		8	.....	6	.....	.....
		12	.....	14	.....	.....
		14	.....	.....	.....	Leak between staves at bilge.
		18	.....	.....	.....	Head bulged flush with chime.
		20	.....	.....	.....	Leak at joint of head.
		24	.....	.....	1.2	Leak between staves.
		4	.....	.....	.....	Seepage through pores; leak at chime.
24	6	10	.....	52	.....	.....
		12	.....	50	.....	Leak between staves at quarter.
		14	.....	.....	.....	Leak between staves at bilge.
		18	.....	70	.....	Head bulged flush with chime.
		20	.....	82	.....	Leak at joints of head.
		28	.....	.....	1.5	Leak between staves.

TABLE 6.—*Individual tests—Internal pressure—Continued.* $\frac{3}{4}$ -INCH BARRELS—Continued.

No. of barrel.	Number of hoops.	Pressure.	Rate of leakage.		Remarks.
			<i>Lbs. per sq. inch.</i>	<i>Drops per minute.</i>	
23a	8	6			Seepage through pores; leak at joints of head.
		12	.....	20	
		16	.....	84	
		20	.....	180	
		30	.....	2.0	
24a	8	4			Leak between staves at chime.
		8	.....	.....	
		16		4	Seepage through pores.
		18	.....	12	
		22			Leak between staves at quarter.
		24			Head bulged flush with chime.
					Leak at joints of head; leak between staves at bilge.
		30		36	Head breaking.
		36	.....	.....	
		38	.....	.....	

TABLE 7.—*Individual tests—Made-up barrels.*

INTERNAL-PRESSURE TESTS.

No. of barrel.	Number of hoops.	Pressure.	Rate of leakage.		Remarks.
			<i>Lbs. per sq. in.</i>	<i>Drops per minute.</i>	
.....	8	4	.....	.....	Leak through defective joint in head.
.....		10	.....	115	
.....		14	.....	.....	Leak at defective joint ceasing.
.....		16	.....	55	
.....		22	.....	56	Head bulged flush with chime.
.....		26	.....	55	
.....		32	.....	130	Head split at joint.
.....	8	34	.....	.....	
.....		4	.....	.....	Seepage through pores.
.....		6	.....	6	
.....		12	.....	130	Leak at chime.
.....		18	.....	180	
.....		24	.....	.....	Head bulged flush with chime.
.....		26 to 36	.....	.....	
.....		38	.....	.....	Leaking in broken stream.
.....	.....	.....	.....	.....	Head forced out.

DROP TESTS.

No. of barrel.	Num-ber of hoops.	Height of drop.	Rate of leakage.	Remarks.
SIDE DROP.				
.....	8	<i>Inches.</i>	<i>Lbs. per minute.</i>	Leak at chime; stave slips. Stave cracked. Hoop slips. Two broken staves.
.....		12	.....	
.....		18	.....	
.....		21	.....	
.....		33	21.0	
DIAGONAL DROP.				
.....	8	9		Leak at chime. Stave slips. Head failing. Head broke out.
.....		12		
.....		18		
.....		21	7.7	



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FLUMES AND FLUMING.¹

By EUGENE S. BRUCE, *Expert Lumberman.*

INCREASING IMPORTANCE OF FLUMES.

The growing scarcity of accessible areas of virgin forests from which timber can be transported cheaply by streams to central points for manufacture has called into being additional systems of handling and transporting logs and timber, as exemplified in the different forms of railroad logging, and in such adjunctive features of logging as donkey engines, overhead cableway skidders, flumes, etc.

Repeated inquiries for information regarding flumes and flume construction are responsible for the present discussion. This method of transportation may be classed as an amplification of log driving, through using water as the transporting medium, but in a much smaller quantity and in a more closely confined and controlled form through the aid of artificial and smoother "banks," as represented by the sides of the flume. It also gives to the operator the additional advantage of being able to direct the transporting agency, under certain fixed limitations, to a desired point sometimes far away from any natural stream of water.

The use of flumes for transporting timber or lumber from localities which at the present time are commercially unprofitable to log will undoubtedly increase in the future. There are large areas of privately owned timber in the higher elevations of the mountainous regions which could be taken out if the cost of logging could be brought low enough to insure a reasonable profit to the operator, and there are a great many localities in the National Forests, which in most cases include the tops of the mountain ranges, where the construction and use of certain types of flumes using the minimum amount of water will make it possible to remove the timber or lumber with the aid of the small streams having their rise in the mountains.

¹ Discusses the use of flumes in lumbering operations and tells how to build them. Of especial value to lumbermen and log drivers.

This increased usage will simply be the logical result of conditions. The removal of timber by flumes from many localities is to-day the only economical method. There are a great many localities where timber is at present being taken out at a loss, but where, if an up-to-date flume had been built at the inception of the lumbering operation, instead of starting with the methods at present used, much more satisfactory results would have been shown.

FORMS OF LUMBER TRANSPORTED BY FLUMES.

The different forms in which lumber or timber is generally transported by flumes at the present time are as follows:

- (1) In logs.
- (2) In piling, mining "stulls," or long timbers.
- (3) In railroad crossties.
- (4) In "cants" or split-log form.
- (5) In lumber "loose" boards or planks.
- (6) In lumber "brailed" or clamped together.
- (7) In cordwood or pulpwood.

There is hardly any limit to the forms in which lumber may be transported in flumes, provided it is of a species that will float and the flume is constructed with due regard for the material to be handled. The logging conditions, species and character of material to be handled, amount of water available for fluming purposes, etc., all have a very direct bearing on the form of flume and the methods used in construction. Thus, in a locality where the supply of water is ample and there is no necessity for husbanding it, a type of flume might be used which in another locality where there was a scarcity or lack of water might be very undesirable.

The very important feature of water supply has, in fact, had much to do in determining the type of flume that is being used in different localities; since where water is plentiful and there is no particular need of being economical in its use, a square or box-like flume of almost any size will do for either logs or lumber, while in other localities it has been found absolutely necessary, on account of the small volume of water available or for other reasons, to use a type of flume which, with approximately one-half the volume of water necessary in the square or box type of flume, will handle practically the same class of material. Thus it is quite common in the Appalachian Mountain region to see box or square sided flumes in use, while in the mountainous western portions of the United States the square-box flume is rarely seen, and the V-shaped flume is the one in general use. Necessity, therefore, has in the past and undoubtedly will in the future be the principal factor in deciding what type of flume shall be constructed.

TYPES OF FLUMES.

There are only two types of flumes in general use in the United States at the present time—

- (1) The box or square upright-sided flume.
- (2) The V-shaped flume.

The square flume is usually constructed along the general lines of the well-known mill flume or artificial conduit used to convey water from the mill pond to the mill for water power or other purposes, but with this difference, that the uprights on the sides of the square or box timber flume are rarely braced across the top of the flume, but instead the top of the flume is left open to afford free passage for logs, wood, or lumber, and the sides are held in place by uprights fastened on the sills or crosspieces on which the bottom of the flume rests, and braced from the outside. (See fig. 1.)

This is the oldest type of wooden flume in use, and is employed to some extent at the present time where economy in the use of water is not of any particular importance. However, the square flume requires more water to operate successfully with the same class of material, and, generally speaking, requires more lumber for construction than does the V-shaped flume. Furthermore, the material being handled is more apt to "jam" (especially the short material) in the square-box type. Owing to the form of its construction there are more joints in this type that are liable to open up and cause "leakage," in case the flume is allowed to stand without water running in it for any length of time, and except where it is desired to combine in one flume the two objects of carrying a large amount of water to be used for some purpose other than fluming below and at the same time to use the flume for the transportation of lumber or timber, it is generally more advisable to use the type of flume which requires the least amount of water and the least average amount of repair. Up to the present that is the V-shaped wooden flume, but it is perhaps not a flight of fancy to predict that it is only a question of time when strong and light "sectional" metal flumes, semicircular in form, that can be quickly taken apart and transported from one point to another and put together and set up again, will be in common use. Metal semicircular conduits, made in sections and easily put together, have already been used in hydroelectric and irrigation projects.

There is a conduit of this character in operation on the Sierra National Forest in California, and the writer sees no reason why a similar type of metal conduit, lighter in construction and somewhat modified in form, could not be developed for log or lumber flumes. The initial cost of construction would, of course, be considerably greater than for a wooden flume, but the metal one would have much greater durability and length of service.

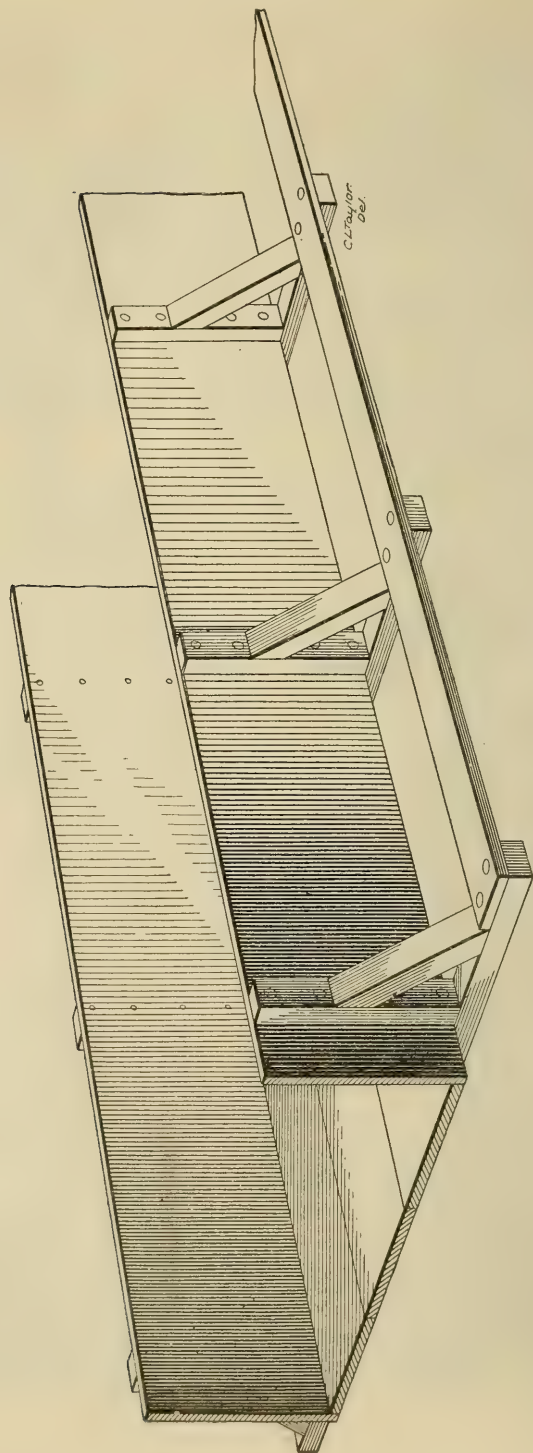


FIG. 1.—Common form of box or square flume.

THE WOODEN V-SHAPE FLUME.

The V-shaped flume is at present the type of flume most generally used in the western portion of the United States, and it has given the most general satisfaction for the transportation of manufactured lumber or timber in its different forms of logs, railroad crossties, cordwood, etc. Some of these flumes have been in successful operation for a number of years, and the writer, who has personally examined many of them, has no hesitancy in saying that, if he were to construct a flume, the V-shaped flume is the type he would erect.

Some of the salient points in which the V-shaped flume excels are:

(1) It can be successfully operated with a less volume of water than any other type, since, owing to the V form of construction, the water is always held confined or "compact," and therefore has the greatest carrying power for the amount used.

(2) There is less likelihood of jams forming, since the narrowness of the flume prevents the material from getting partially crosswise and forming a "brace" through the ends, "wedging" or pressing against the sides of the flume. This is a feature especially desirable when handling short material. The narrow formation of the V-shaped flume keeps the timber running "straight," and according as the volume of water in the flume is reduced the formation of the V keeps the water confined in the smallest possible triangle down which the sides of the flume compel the material to travel.

(3) In fluming logs or round timbers the rounded portion of the log settles well down into the V. The water thus confined between the bottom of the stick and the sides of the V constantly tends to lift the log, and this keeps the stick from settling down or rubbing hard against the sides of the flume. In a square flume, on the other hand, the same amount of water could run on both sides of the log and not beneath and would so lose the tendency to "lift" through lack of proper confinement.

Thus if a log or stick of timber is large and heavy, it may sometimes nearly fill the V-shaped flume and occasionally touch both sides. But whenever this occurs the log has the pressure of the full volume of water which the flume can carry backed up behind it to force it along, and the V formation keeps the stick running "straight ahead," so that there is very little opportunity for the water to spread out or run around or get by the stick without taking it along with it. Its transportation is further aided by the uplift of the partially confined water, running around and under it, that is trying to find an outlet or relief from the pressure of the water behind, which must either aid in forcing the stick along or run over the top of the flume.

(4) In cases where it is necessary to have an unusually abrupt descent in some portions of the grade, the V-shaped flume is best adapted to serve as a "slide" or "slip," or "chute," since it is less likely to become jammed, while the material being handled is held by its own weight in proper position in the center of the V. In a great many localities this particular feature of control of the log or stick of timber when it is "coasting" will be found very necessary in handling material from the higher mountain slopes, especially in places where it is impossible to maintain a steady and equable grade from the top to the bottom of the mountain without too great expense, and where it may be necessary to have a form of construction that will carry logs or timber safely for a long distance when the grade is so abrupt that it is impossible to maintain a sufficient volume of water in the flume to prevent the material from rubbing or sliding along on the sides and bottom. In such localities and under such conditions the V-shaped flume, when strongly constructed so as to combine both the objects of flume and chute, has been and will be found altogether the most desirable.

DEGREE OF ANGLE FOR "V"-SHAPED FLUME BOXES.

In the construction of the sections or "boxes" in V-shaped flumes a number of different degrees of angles have been used in the past. In some instances the constructors have used an angle as low as 70 degrees, while others have constructed flumes with an angle of 110 degrees. The results of experience and the consensus of opinion, however, are that the 90-degree or straight right angle is the most satisfactory form of V-box construction for all purposes, and this is the degree of angle that is referred to when speaking of V-shaped flumes in this bulletin unless otherwise specifically stated.

METHODS OF CONSTRUCTING THE "V"-SHAPED FLUME.

There are many different methods and styles of construction used in building V-shaped flumes, varying according to the kind of material to be handled. In some cases the brackets or frames that support the sides of the V are made from round pole wood simply flattened on one side so as to give an even surfaced support to the boards forming the "lining" or inside of the V, while the sills, stringers, braces, and trestling may be constructed from small round timber or poles, leaving only the lining or inside of the box to be constructed from sawed lumber. The form of construction of the different sections of the flume, or, as they are called, "boxes," also varies in length from short ones of 6 feet up to those of 20 feet. In the construction of the lining or inside of the boxes, lumber of variable thickness and width is used. The boxes are sometimes made of only one thickness of boards simply joined together, but more commonly

the lining of boxes is constructed with two thicknesses of boards with the joints broken by varying the width of the boards, as shown in figure 2. Another form of box construction is by the use of a single thickness of boards with "battens" to cover the joints, the battens being spiked over the joints on the outside in the sections between the brackets or arms, as shown in figure 3. There is still another form of box construction in which the battens are continuous. (See fig. 4.) In such cases the battens are "cut in" or set into the arms or brackets on the outside of the V, thus making a continuous "broken joint."

There are certain individual advantages in each of these different styles of box construction, and the right one to use is a question which the prospective operator must always determine for himself. The use of the continuous battening running under the arms requires some cutting into the bracket frames or arms in order to let the battens pass through them, and consequently, to a certain extent, weakens the arms. This usually necessitates a heavier arm than would be required if the battens only reached from one arm to another and were spiked over the joint entirely independent of the "arm." On the other hand, the continuous battens are held firmly in place by the arms and braces, and it is almost impossible for battens properly put on in this manner to get out of place while the arms and braces are firmly in position.

The use of the double-lined box with joints broken is contended for by some operators on the ground that it is always necessary to replace the lining of the boxes occasionally on curves and in places where the passage of lumber wears most rapidly. It is also contended that the doubled box retains moisture much better between the two linings and, therefore, will permit of the flume standing idle without any water running in it, for repairs or other reasons, for a much longer period of time without the boxes becoming thoroughly dried out and "checking" so that the flume will leak, or warping out of shape and position, or drawing the nails used to hold the lining in place. The battening between the different arms or frames makes it possible to use almost any width or thickness of material for this purpose. It can be put on or taken off without interfering with any of the other forms of construction, and this feature also has its ardent supporters.

TRIANGULAR BLOCKS IN THE BOTTOM OF THE "V."

In some instances it has been thought advisable to fill the bottom of the V in a flume with a triangular section of wood sawed in such form that it would fit snugly into the bottom of the V on the inside. Some constructors claim that this block serves the twofold purpose of reducing the amount of water necessary in operating a flume and

also strengthens the flume itself. It is not believed, however, that the benefit to be derived from this form of construction is sufficient to compensate for the increased cost of construction and the greater

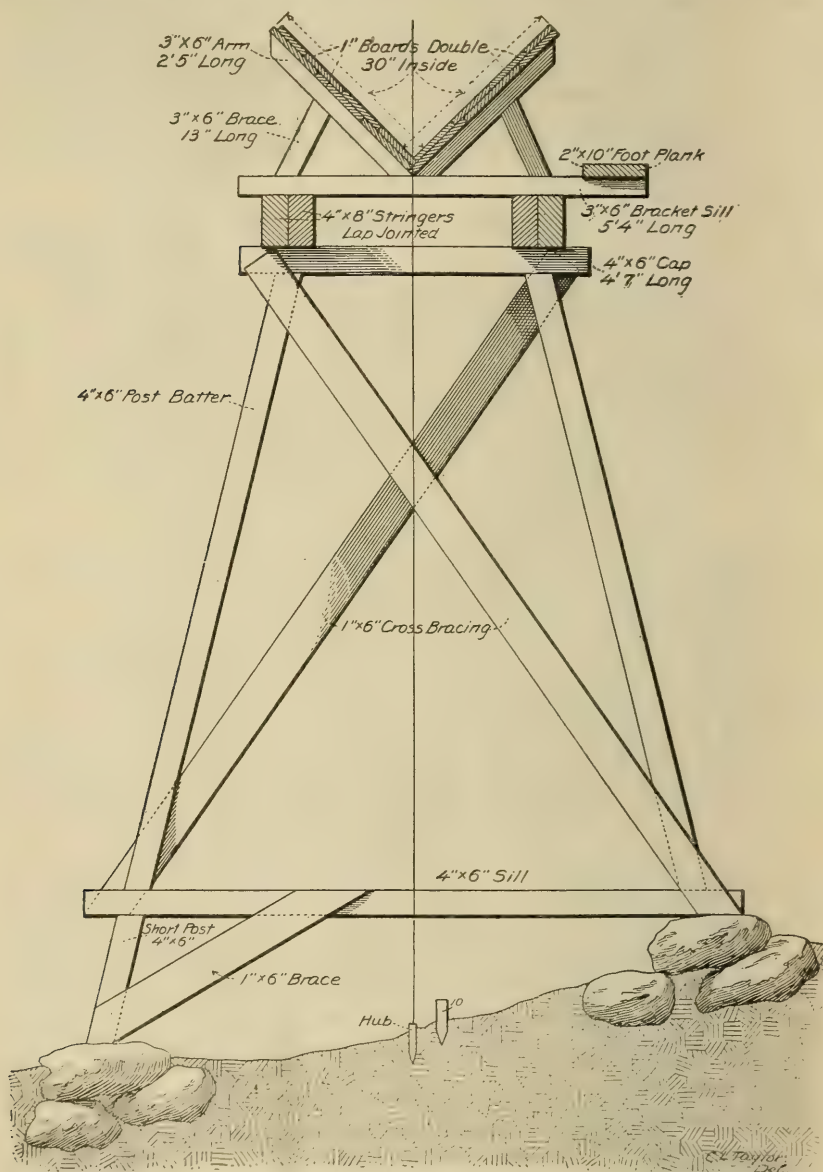


FIG. 2.—End view of V-shaped flume, showing method of construction and double-lined box.

amount of material necessary. The prospective constructor should be governed by the location, kind of material available for construction, duration of life of flume desired, and material to be handled in deciding what type of construction he will adopt.

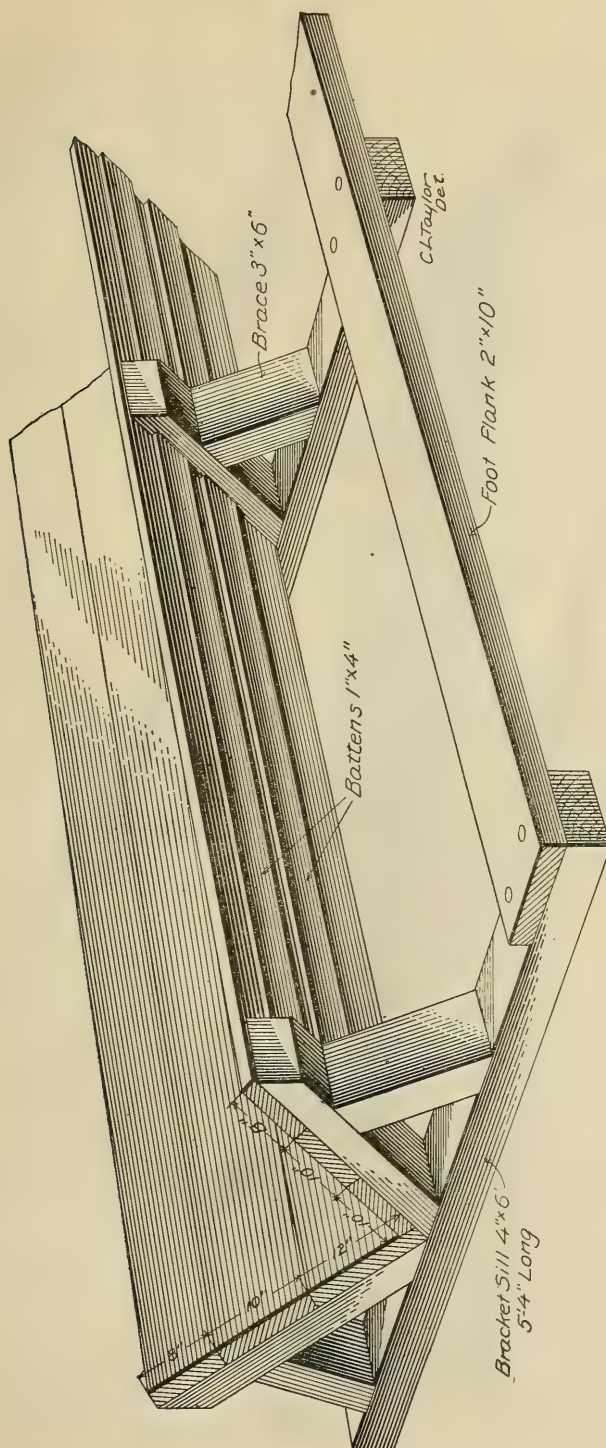


FIG. 3.—View of flume showing dimensions of different parts.

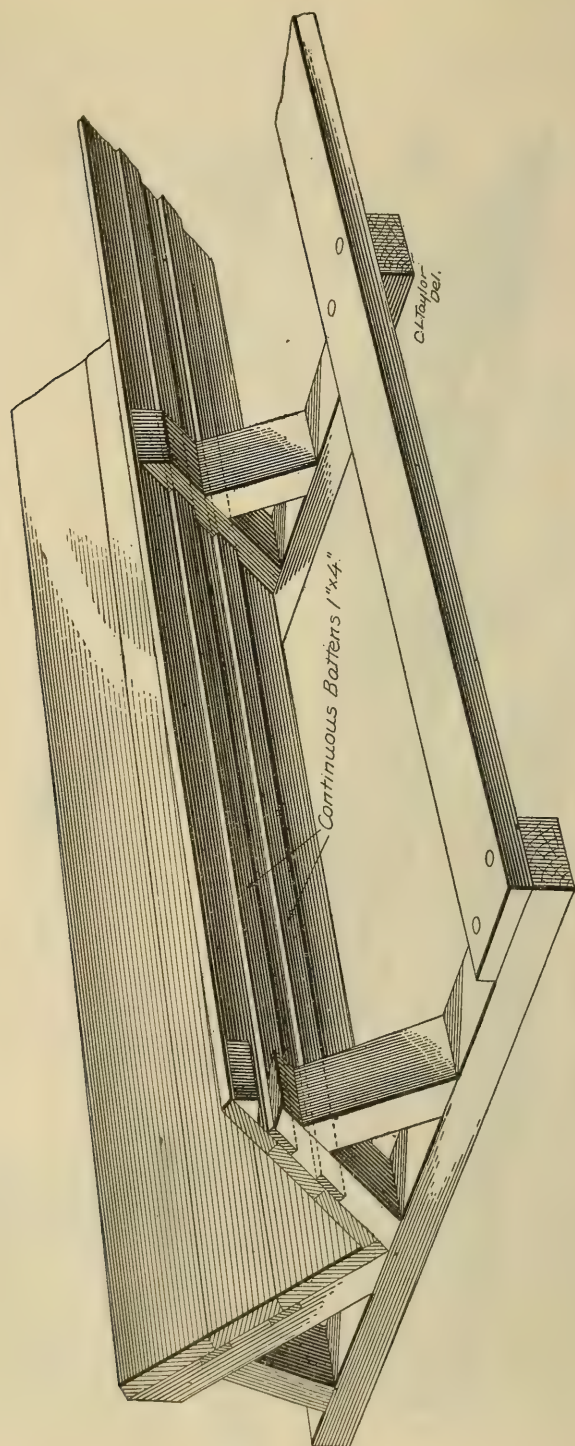


FIG. 4.—Side view of a flume constructed with continuous battens.

SIZE OF FLUME.

The kind of material to be handled is a prime factor in determining the size of a flume. If a 30-inch V-shaped flume would satisfactorily handle the material, there would be nothing gained by going to the extra expense of constructing a flume with a V of 48 inches. On the other hand, it is always good policy to construct a flume large enough to carry sufficient water to handle the material desired with certainty and dispatch. For railroad crossties, cants, poles, cordwood, etc., the 30-inch flume is usually large enough, wherever there is a sufficient volume of water available to fill the flume two-thirds full, while for the handling of logs, piling, long timbers, or "brailed" sawed lumber it is usually advisable to have the flume constructed with the sides of the V from 40 to 60 inches in height, according to the volume of water available and the size of the material to be handled. This is also a feature in flume construction in which the prospective operator can save money by not constructing his flume larger or in any more expensive form than is actually needed, since every additional inch in height means the use of more lumber in construction, and is consequently an added and unnecessary cost.

METHODS OF CONSTRUCTION.

For the benefit of those who are entirely unfamiliar with flume construction, a description of some of the salient points may be of interest. It is usually advisable to erect a small sawmill at or near the upper end of a flume location to saw out the lumber needed for construction. This material can be floated down the flume as fast as the latter is constructed to be used for further extension until the whole flume is finally built. This obviates the necessity of hauling the construction material, so far as lumber or timber is concerned, up grade from the nearest point at which it can be secured, and oftentimes cuts out long-distance transportation charges and generally reduces the cost of construction, although it usually necessitates the construction of a passable road for the purpose of hauling the necessary boiler, engine, and sawmill machinery to the upper end of the flume or place where the construction lumber is to be manufactured.

It will be apparent that the nearer this lumber manufacturing point is to the upper end of the flume the more economical will be the construction, as it is much cheaper to float the lumber down the flume to the place where it is to be used in construction than to haul it up grade by teams. Since the flume can usually be filled with water as fast as constructed, where battens are used, there is no great benefit derived from using seasoned lumber for construction purposes, although when a flume is constructed of seasoned lumber the introduction of the water causes the joints to swell and become

tighter than where unseasoned lumber is used. The power used for operating the small mill to cut out the necessary timber and lumber to construct a flume is usually the ordinary portable type of boiler and engine, sometimes in the combined form. There will be found cases and localities in which the use of an overshot or an undershot water wheel will more economically furnish the necessary power, where there is an ample supply of water and favorable conditions for its being used for this purpose, and there will be some cases in which electric power to operate the mill, transmitted from a convenient line of some electric-power plant, will be found most economical.

After the mill is installed it is advisable to use prepared frames, "forms," or miter boxes in cutting the brackets, frames, or arms with the "power saw" into the desired length and shape, and also in cutting the braces, stringers, sills, overlays, and material for use in trestling. Experience has demonstrated that the material can be shaped at the mill and transported to the place where it is to be used by means of the water in the flume much more economically than in any other manner. It is advisable to prepare the frames and arms at the mill ready for setting up, and flume them in their finished form down to the point where they are to be used; this method requiring only that they be placed and fastened in position after arriving there. (Fig. 5.)

A CAREFUL SURVEY NECESSARY.

An accurate and careful survey of the proposed line of flume construction is a prime necessity and often a great economy. A needlessly expensive survey should always be avoided, but accuracy of grade and careful and reliable "leveling" is imperative in order to insure lasting flume construction. The equalization of grade is very advisable wherever it can be accomplished without too great an expense. And right here a practical knowledge of the comparative benefits to be derived from having a steady or an even and moderate grade, considered in relation to cost, is of great value. The grading of soil in knolls or hillocks or ridges along the prospective flume line is advisable up to a certain point, if necessary to maintain a reasonably steady grade for the flume. A careful preliminary survey followed by a location survey, using a transit and level, will make it possible to obtain a reliably constructed profile map which will show to the prospective operator what the grading should be at different points of his line. It is always best to know just what the grade is going to be when completed, and approximately what it is going to cost, before starting the construction work. No detailed estimate of the cost of survey is included here, for the reason that the wide range in conditions where flumes might be constructed would make any set figures unreliable and possibly misleading. A

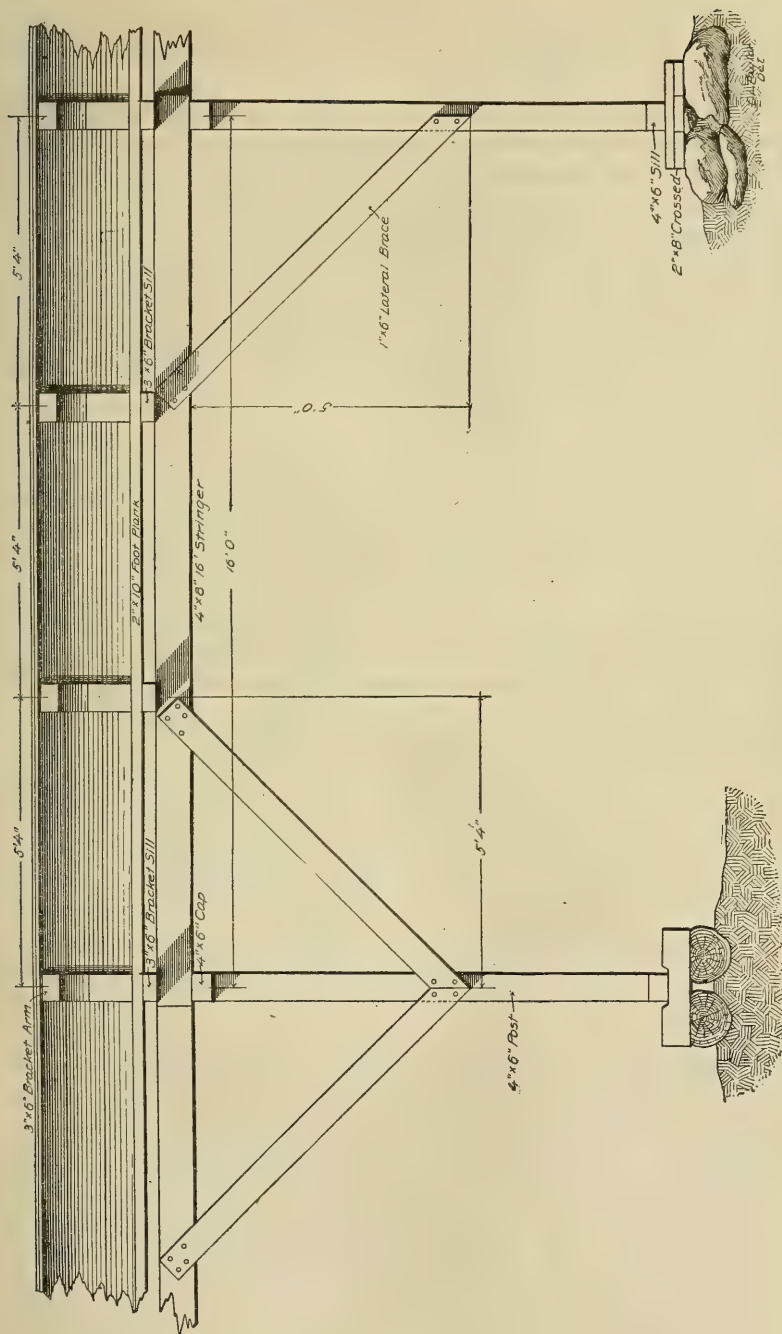


FIG. 5.—Side view of V-shaped flume showing method of construction and lateral bracing.

reliable survey, however, is absolutely necessary, and a carefully constructed profile map highly desirable before construction begins. The cost of the completed survey would be comparable to that of a branch railway location.

The blasting out of rocks and bowlders or projecting points of bluffs is sometimes advisable and necessary in order to reduce curvature and allow the flume to run in as direct a line as possible. This reduces the danger of "jamming" and makes it possible to handle longer material without its "binding" as a result of the ends "pressing" against the lining of the flume on the outside of the curve while the middle of the stick presses against the lining on the inside. Just what is necessary to be done in this respect can best be calculated by using a carefully prepared profile map made from an actual survey of the proposed flume line.

GRADES.

The matter of grade in flume construction is one of great importance. It is not always possible to vary the location so as to maintain an equable or steady, even grade in all portions of a flume line, but wherever it can be accomplished without incurring too great an expense it should always be done. Flume operators have found the question of satisfactory grade to be one of the most important features of successfully fluming material, since where there is a stretch of comparatively flat grade the supply of water may be ample to nearly fill the flume, but upon arrival at a point in the flume line where the descent is very abrupt, the accelerated speed of the water reduces its volume to a small amount in the bottom of the flume and, consequently, results in the flumed material "rubbing" or "sliding" down the descent for a long distance on the sides of the V. Such action wears out the lining very rapidly, necessitates its being frequently renewed, and produces a dangerous condition through the liability of the material to jam and pile up, and either be thrown out of the flume or break it down as a result of the increased weight.

In general, the lowest grade that is considered satisfactory for successful operation is approximately 1 per cent, or 1 foot in 100 feet, but it is better to maintain a grade of from 2 to 5 per cent when possible. The maximum grade that can be used runs up to a very high pitch; some flumes have been successfully operated for a short distance at a grade of 30°, but such a steep grade is very undesirable, as it is usually impossible to maintain a sufficient volume of water in the flume. The most satisfactory results in fluming will be obtained at from 2 to 10 per cent grade, and it should be held below 15 per cent whenever possible:

TRESTLING.

In maintaining the steady or even grade of a flume it is nearly always necessary to do more or less "trestling," in order to avoid unevenness in the line, reduce distance and abrupt curvature, and hold the general grade of the flume at the desired height. (Pl. I.) Here, again, the necessity of a careful survey becomes apparent, for without a knowledge of just what the height of the trestling needs to be in each successive 12 to 16 foot distance, it would be impossible to know just what length the bents and braces of the trestling should be cut, or just what "pitch" should be given to the bracing legs of the trestle, or just where the foundation "stepping" should be placed in order to hold the top of the flume firmly in the desired position.

I can not make the question of the necessity of a careful survey too important, especially for a mountainous or rough and rugged country, which is the type of locality in which considerable trestling is most likely to be used. In this connection, it is sometimes very advisable in the interest of economy, and necessary from the viewpoint of successful operation, to grade out the earth along the sides of ridges, where this can be done cheaper than trestling can be constructed in other localities along the line, for its effect in maintaining the desired grade. Also, grading out is in some cases desirable in order that the top of the flume, when completed, may be practically on a level or a little below the earth's surface, at least on one side, so that logs or heavy timber to be shipped may be "loaded" into the flume without having to use a needless amount of energy to get them there.

In many cases the amount of money spent in loading material into a flume set up unnecessarily high above the earth's surface has eventually cost the operator much more than it would to have lowered his flume by grading or slightly changing its course in the first place. This is a feature that should not be overlooked.

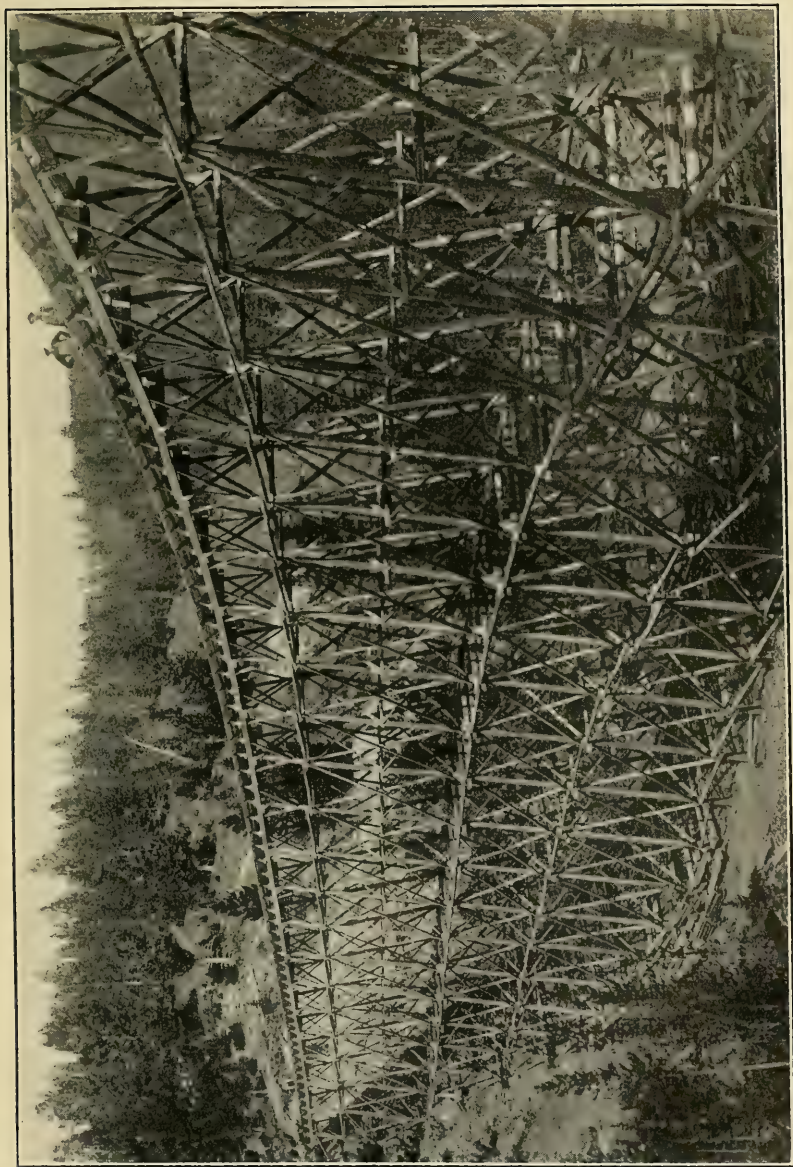
CURVES.

In the location of a flume line it is advisable to avoid abrupt curvature as much as possible. Where the contour of the country makes curves or bends in a flume necessary, they should, whenever possible, be on long, even lines. (See Pl. II.) A sharp curve in a flume throws the weight of the material and the water by centrifugal force to the outside of the curve, and the abrupt bend in the flume has a tendency to dam up or hold back the water. The material is thus much more liable to jam or block on an abrupt curve than on a gradual one. When a jam occurs in the flume the blocked material acts as a dam, and after several sticks or pieces of lumber have stopped, the front end of the block or jam rests solidly on the sides and bot-

tom of the flume. In consequence the water is forced over the sides, and usually throws the material out of the flume, especially if the curve is on an abrupt descent, or else the constantly increasing weight of the jam breaks the legs of the trestle, if there be one at this point, or perhaps causes the whole framework to collapse. It is then often a matter of considerable loss of time and expense before the flume is repaired and again ready for operation. The degree of curvature should be kept as low as practicable, and should rarely be permitted to exceed 20° .

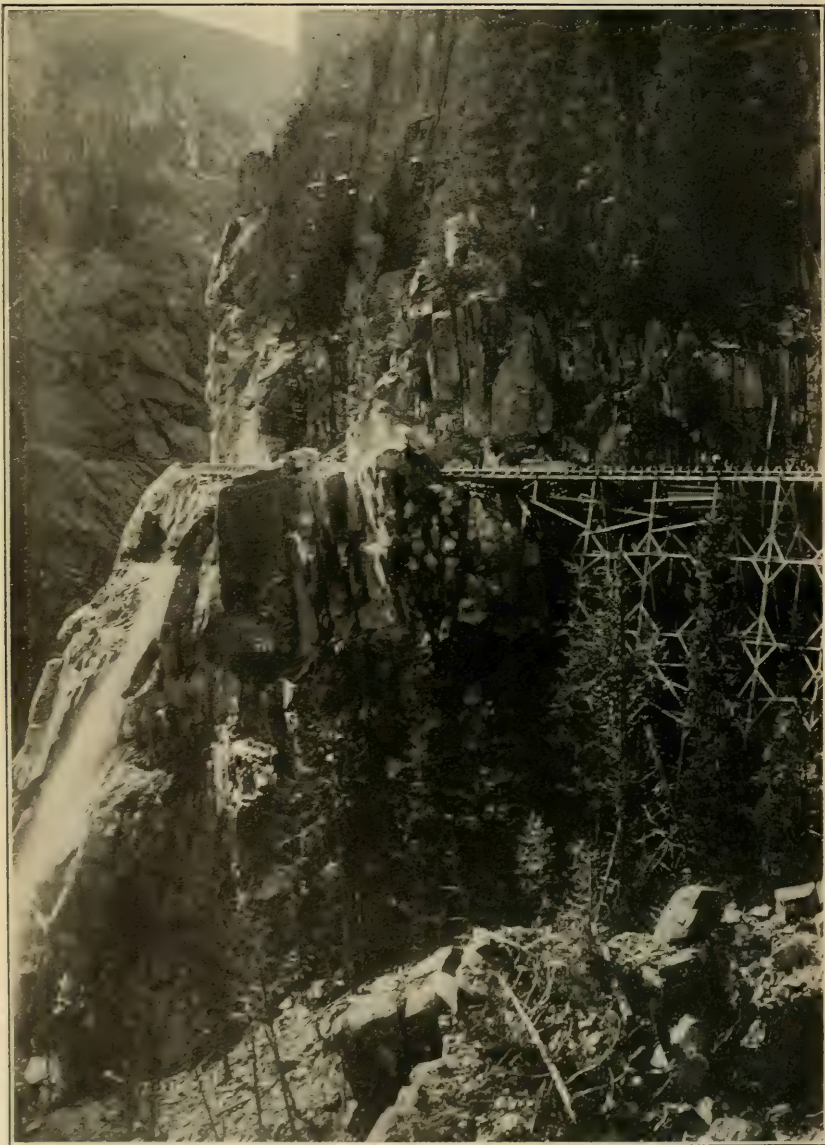
The length of material to be transported is an important factor in deciding the degree of curve that can be used, since very long material can not be successfully transported in a flume having a very abrupt curve. The curve would have to be sufficiently open to allow the chord of curve to be represented by the length of the longest material desired to be handled, with a small allowance for clearance. No curves should be used in construction that will cause the material to "bind." The longer the material the less abrupt curvature is permissible, and vice versa. The bracing of a flume on the outside of the curve necessarily should be more rigid and stronger than on the inside, since the greater pressure "thrust" or "throw" of the water and material being shipped is toward the outside of the curve. Very abrupt curves require increased bracing and the placing of the arms and brackets at shorter intervals, in order to hold the flume in its proper position.

Shorter "boxes" and closer spacing of "bents," "arms," and "braces" on curves.—Where the topographic conditions in a locality are such that it becomes absolutely necessary to have abrupt curves in a flume, it is advisable to reduce the length of the boxes and correspondingly shorten the distance that the "bents," "arms," and "braces" are placed apart, for the twofold purpose of evening up or reducing the sharpness of the angles in the joining of the boxes on the curve, and also to give more stability and strength to the flume at the points where there will be the greatest strain upon it. It will be apparent that long boxes in a flume at a point where there was an abrupt degree of curvature would necessitate sharper changes in direction than would shorter boxes, thus producing something in the nature of square corners. These corners, particularly if there were a rapid descent in the flume line at such curve, would have an effect something in the nature of a dam or stoppage in the flume, and as a result cause the water to slop over or run out over the sides. In addition, all material coming down the flume, as a result of the quick change in the direction of its course, would "strike" sharply against the outside "corner," and the continual pounding of the material against the side of the flume would be very likely to jar and eventually loosen up the joints at this point, throw the flume out of alignment,



A FLUME TRESTLE 775 FEET LONG AND 75 FEET HIGH CONSTRUCTED OF ROUND MATERIAL-

Only the stringers and boxes are made of sawed lumber.



AN UNAVOIDABLE, ABRUPT CURVE.

When material is thrown from a flume at such a point as this it is practically a loss. Note the men raising the sides of the "V." Trestle is constructed of sawed material.

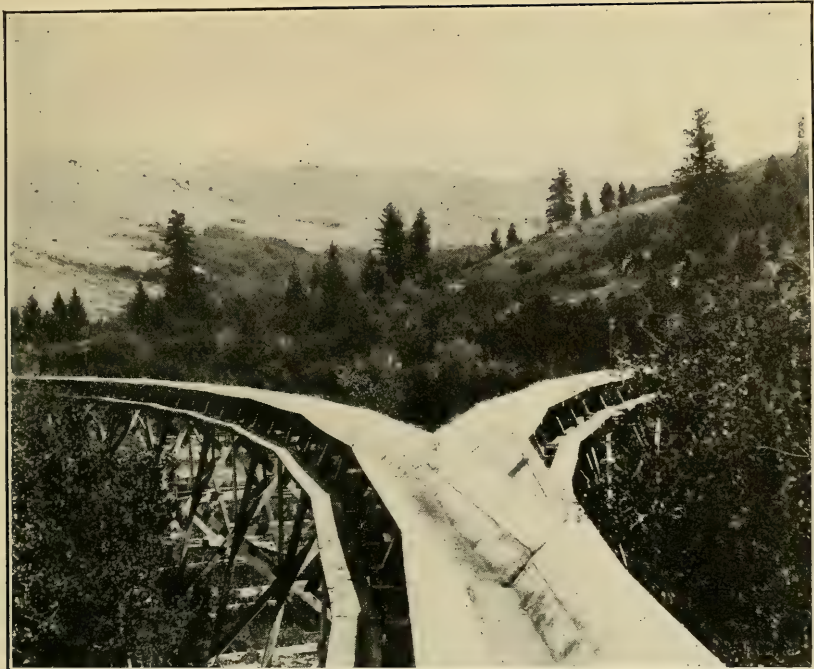


FIG. 1.—A BRANCH FLUME, SHOWING METHOD OF CONNECTION WITH MAIN FLUME.

In this case the branch is closed off by the use of two "lining" blanks.

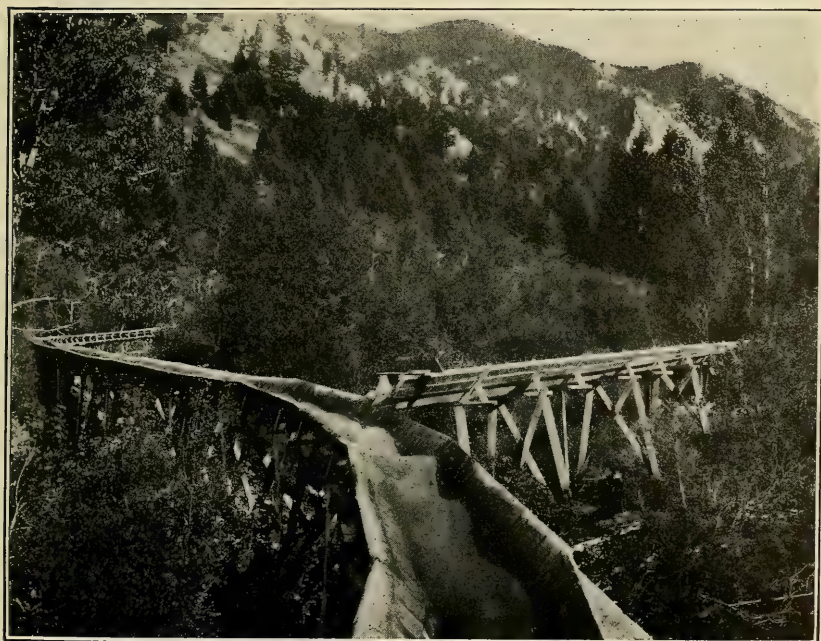


FIG. 2.—A FEEDER FROM A SIDE CREEK.

Notice cheap form of construction.



A TUNNEL THROUGH A LEDGE TO AVOID CURVATURE.

In this case it was cheaper to tunnel than to blow out the entire ledge.

and cause it to leak badly, or at least batter and wear it out more rapidly than would be the case if the curve were more gradual. More than this, there is always the increased danger of jams or blocks occurring in the flume at such points. It is for this reason that shorter boxes, which will more evenly graduate the curve, are desirable.

There are no hard and fast rules that will correctly fit any and all conditions, but in general on curves of from 6 to 10 degrees, the boxes in a V-shaped flume should be "jointed" at least once in every 12 feet with corresponding spacing of bents and reinforced bracing. On curves exceeding 10° and less than 15° the box should be jointed at least once in every 8 feet of length, and on curves of more than 15° boxes should be jointed at least every 6 feet, with corresponding spacing of bents and reinforced bracing in every case.

As said before, but repeated now for the sake of emphasis, whenever it is possible without incurring too great or prohibitory expense, very abrupt curvature should be avoided in flume construction, and it will usually be found a wise policy to go to a considerable additional expense in excavation work or blasting out of rocks and ledges in order to reduce curvature to a satisfactory degree. In every case where extreme curvature is unavoidable the foundation footings upon which the flume is supported should be carefully placed on very solid material, in order to withstand the continued impact and jar of the logs striking the sides of the flume; and the entire flume construction should be strongly reinforced at such points, not only by shortening the length of the boxes and placing the bents, side arms, and braces closer together, but also, if trestling is necessary at such points, by strongly reinforcing the trestle bracing, both "lateral" and "sway."

Increase in height of sides of "V" on abrupt curves.—It is advisable on abrupt curves to increase or raise the height of the V on the outside of the curve, in order to cause the material being shipped to drop back into the flume when it tries to "climb," as it always does in such places, and thus prevent it getting on top of the side of the flume and "riding" until it strikes some little projection or joint and forms a "block" or "jam." (See Pl. II.) On very sharp curves it is usually advisable to raise both sides of the flume a little higher than is necessary on tangents and on equable grades, in order to retain the water in the flume, especially if there be a very abrupt descent at the point of curvature, as is sometimes unavoidably the case. The raising of the sides necessitates only the use of a longer arm and additional height of the lining of the flume at such points.

FEEDERS.

Feeders constructed at various points along a flume line are usually necessary in order to maintain the requisite amount of water and to furnish a sufficient volume to operate a flume successfully on

the different grades. A volume of water that would be ample to handle or float the material satisfactorily on a long stretch of flat grade might not be sufficient to furnish an adequate volume to prevent the material from rubbing or striking on the bottom in a section of the flume where the descent was more rapid; and it is also usually necessary to have feeders coming in at different points along the line in order to replace the water that has been lost as the result of leakage or slopping at the abrupt curves. The side feeders are usually brought in from small side creeks by means of a short line of V or square flume constructed from a small dam made in a side creek at some point where there is sufficient descent to carry the water down into the main flume. (See Pl. III, fig. 2.) The number of feeders, the distance apart, and the points where they shall be brought in are determined by the necessities of each case.

Where a main flume line is following closely the bed of a creek having considerable drop, it is usually advisable to take the water from the creek itself by means of a feeder flume having a slight down grade until it intersects the main flume. This can be done by blocking up under the feeder flume, either by trestles or by any other economical and convenient form of foundation, until its end will reach the top of the V. It is usually advisable to make the feeder line as direct as possible and thus avoid increased construction. Feeder flumes do not have to be as substantially constructed as the main flume lines, since nothing except water is conducted in them, nor is the form of construction as important for the same reason. Therefore the single-thickness square-box type of flume is often used for this purpose. Any method of blocking in under a feeder flume that will furnish a substantial foundation is permissible. Here again, however, as in the trestling under the main timber or lumber flume, too cheap construction, trestling, or blocking is false economy, as the work should always be stable enough to be lasting.

TUNNELING.

Tunneling through such obstacles as sharp ridges or projecting bluffs has sometimes been found advisable, economical, and necessary in order to maintain a proper and desirable grade, shorten distance, and prevent too abrupt curvature. It is sometimes cheaper to tunnel for a *short* distance through an obstruction than to trestle for a *long* distance in order to raise the line over it or to put in a long curve to get around it. It is also sometimes cheaper to tunnel through a ridge or projecting point of rocks than it is to make an open cut. This has been demonstrated by the practical experience of a number of operators. (See Pl. IV.) A tunnel should be carefully located by survey, so as to be certain that it will be very close to the desired grade in order to reduce the amount of necessary excavation to the

minimum. This will permit of the "stringers" for the flume resting on solid foundation in the bottom of the tunnel, which, once solidly placed, usually requires little or no repair.

There is no danger of flumes constructed through tunnels being filled as a result of snowstorms nor affected by contraction or warping as a result of the sun's rays. The principal danger resulting from construction through tunnels is that of material falling into the flume from the top of the tunnel, unless it is protected, when the tunnel is through loose earth, by framework and lagging over the top of the flume. This danger, of course, does not exist where a tunnel is driven through solid rock, as the rock itself furnishes a stable roofing. And if the earth through which the tunnel is driven is solid, it is not always necessary to go to the expense of setting up frames and placing "lagging" over the top of the flume, since what small amount of loose earth does drop into the flume as a rule will quickly be dissolved and washed away by the running water. It is usually possible, by varying the flume-line location, to get around obstacles without going to the expense of driving a tunnel through rocks and ridges, but there will be found cases in which it is impossible to secure a satisfactory location and at the same time maintain a desirable grade and avoid very abrupt curves without resorting to tunneling.

SMALL HOLDING RESERVOIRS AT DIFFERENT POINTS OF FLUME.

It is sometimes advisable to have small holding reservoirs or "catch basins" constructed at different points along a flume line, where it can be done without involving prohibitive expense, in order to provide an additional storage place for logs, crossties, or rough lumber. The upper end of a flume may have to be used to its fullest capacity for a short time in the spring, when the melting snow and early spring rains will furnish a sufficient volume of water to transport material down to the upper end and past more abrupt portions of the flume, and sometimes when this rapid shipment is going on, loading or storage facilities at the lower end of the flume may become so congested that it is impossible to take care of all the material, even temporarily, at that end.

Under such conditions it is sometimes possible to construct at different points along the line of the flume small storage reservoirs, which can be cheaply formed by damming up some small stream or using some small natural pond favorably located along the line, thus diverting the class of material not desired to be handled clear through at once into such reservoir, and taking it out and shipping it later with the aid of the increased volume of water available at this lower point of the flume. The prospective operator must always be his own judge of whether this is necessary and desirable, and should properly take into

consideration the possibilities of such features being needed when locating the general line along which his flume is to be constructed.

Where such features are carefully looked up before the final location of a flume line is settled and flume construction has begun, it is sometimes possible slightly to vary the location of the proposed flume line so as to bring it to the desired grade to be successfully operated in connection with a cheaply constructed holding reservoir, without in any way decreasing the transporting capacity of the flume. It is also sometimes advisable to construct a small reservoir or "catch basin" at the foot of an unavoidably long and very abrupt grade, so that when the material being shipped leaves the flume or slip it will strike into a pond of water and thus avoid being split or broomed. Sometimes the reservoir and its additional feeders will furnish enough water to permit the flume line to be carried on an even grade from the point of the "catch basin" or small reservoir at the foot of an abrupt descent to its destination. In such cases the reservoir and feeders act as equalizers of the volume of water in the flume.

It has been found necessary in some instances to have small storage reservoirs, provided with a small gate that could be quickly closed or opened, located at different portions of a flume where no feeders were available, in order to obtain a sufficient volume of water to carry the material being handled to the next station or reservoir, or to its destination. Where conditions obtain that make this kind of an operation necessary, it is usually advisable to have the mouth of the "intake" considerably wider than the flume, which permits the water to go into the flume opening in a wide unobstructed flow.

When operating under such conditions it is always advisable to let the water in the flume run for a short time before any material is shipped. Otherwise the material receives a strongly accelerated movement on the rapid descents, and is therefore carried by its own weight and momentum into the slower moving volume of water in the flat grades at a greater rate of speed than the water is moving, and consequently runs slightly faster than the water. For this reason the water should always be allowed to run in the flume for a sufficient time to be sure that the latter will be filled its whole length, or at least to the next station below, before any material is started on its way from the shipping point above.

RESERVOIR PONDS AT HEAD OF FLUMES.

It is advisable and oftentimes necessary to make a small artificial pond or reservoir at the upper end of a flume in which to "land" or "bank" the material to be shipped, especially when handling logs, railroad crossties, or heavy unmanufactured material of any kind. Conditions sometimes make it possible to use the ice on a pond of this

character at the head of a flume as a banking ground in the winter or a place to land and hold the material to be transported by the flume in the spring during the time when the cold weather and ice prevent the flume's use.

When a pond is being used for this purpose, if there is more than one kind of material being put on the pond, it is usually advisable to place substantial booms on the ice between the different classes, so as to keep them from getting mixed when the ice in the pond thaws out, and further to enable the different classes of material to be shipped according to the desires of the operator or the needs of the manufacturing plant, if there be one located at the lower end of the flume. If the depth of the pond is sufficient, it is usually more economical to get material into a flume from where it is landed on the pond, which requires only the separating or "breaking down" of the different piles or skidways, than it is to get material into the flume when piled alongside. In the latter case some of it will usually be at a distance from the flume, thus necessitating either its being loaded onto a dray or carried by hand and dumped in. It is much more economical to float the material into the flume from a reservoir when this is feasible.

Probably the most noteworthy example in the United States of the construction of a storage dam and flume combined is the Azis-cohos Dam, on the Magalloway River in Maine. A particularly interesting feature of this construction is an "adjustable intake" to the V-shaped flume, which is so arranged that it can be quickly raised or lowered to suit the varying heights of water in the storage reservoir above the dam. The adjustable flume intake has a range of 25 feet. This flume, which is a wooden V-shaped one built on a large scale, carries the logs from the storage reservoir above the dam down past the rapids below the dam on the Magalloway River to the still water, where they are released from the flume into the river to be floated on down to their destination at the mills on the Androscoggin River. Only enough water to bring the river up to the required driving "pitch," in addition to that which passes through the flume, is released through the "sluice gates."

In July, 1913, this flume was handling logs from 12 to 60 feet in length at the rate of approximately 1,000,000 board feet in 10 hours, with the adjustable intake working satisfactorily at a point 15 feet below the maximum water height. The principle of this construction is applicable to public or private irrigation projects, or wherever it is found necessary to take logs or timbers from a high reservoir dam, having greatly varying heights of water at different seasons of the year, to some more convenient place for manufacture or further transportation, using only the minimum amount of water necessary to get the material to such point.

BRANCH FLUMES.

Material is sometimes brought to the main flume from side gulches, ravines, or small watersheds by the use of what are generally known as "branch flumes." (See Pl. III, fig. 1.) Their use is advisable where there is a side valley with a sufficient volume of water available and containing enough material to make the construction of the branch flume warranted as being the most economical means of getting the material to the main flume. Branch or side-line flumes of this character are usually constructed practically the same as the main flume, except that it is usually advisable, if a mill has been constructed at the upper end of the main flume, to saw the lumber at the already constructed mill and flume it down to the most convenient point of the main flume, where it is taken out and from there hauled by team to the point at which it is to be used in constructing the branch. Unless the branch were a long one, it would hardly justify the erection of a mill for the sole purpose of sawing out sufficient lumber to construct it.

It is sometimes possible to take down a branch flume after the material in a gulch, small creek watershed, or ravine has been cleaned up, and move it to some other point and again set it up for use. Branch flumes are usually brought out and connected up with the main flume, as shown in Plate III, figure 1, so that the material being handled will come out into the latter on a gradual curve on the same level. Branch-flume lines also act as feeders and serve to maintain the volume of water necessary to operate the main flume. It will in some cases be found necessary to use the total volume of water available from two or more streams in order to have sufficient volume to carry the material forward on the lower grades. In such cases it is sometimes possible to bring both the material and water together at the main flume by constructing the branch V flumes very strongly, and using them much as a wet slide is used to slip the material, by the aid of the small amount of water available, from the higher elevations down to where a sufficient amount of water has accumulated to float it to its destination.

SWITCHES AND Y'S.

Switches and Y's are sometimes necessary in the lower end of a flume when it is desired to direct material to different points for piling or to a planing mill, if it be lumber, or to storage places if it be railroad ties, cordwood, or mining stulls, when, as sometimes occurs, the shipping or transportation facilities are not adequate to take care of the amount of material being handled daily by the flume. (See Pl. V.) When this is the case and rough material is to be handled, it is advisable to gradually raise the lower end of the flume on trestles, so as to have the desired space between the flume and the surface of the earth

to hold material diverted. Several switches or Y's scatter the material being shipped over whatever area it is designed to use as the storage place until such time as the material is to be manufactured or loaded onto railroad cars for transportation elsewhere. Plate V shows the general idea of the storage Y's.

THE USE OF "SNUBS" IN UNLOADING MATERIAL FROM A FLUME.

The use of a "snub" or temporary block in a flume so constructed that it will act as a dam which fills the flume to its utmost capacity and forces the material that is to be unloaded at this point to float at the highest possible elevation is often very useful in removing the material from the flume, particularly when it is desired to take it out over the side onto a loading platform alongside a railroad track, as shown in Plate VI, figure 1. The form of construction of a snub is shown in figure 6. With short, light material, such as railroad crossties, a snub under certain favorable conditions will throw the product being handled out of the flume without any assistance, although it is always good policy to have a man on hand to be sure that there will be no failure in getting the material out of the flume lest it cause a serious block or jam that may eventually break down the flume, and cause more expense than it would to keep a man on the job all the time. A form of snub working unassisted is shown in Plate VI, figure 2.

REINFORCEMENT OF FLUMES AT POINTS WHERE EXTENSIVE LOADING IS TO BE DONE.

Flume construction should usually be strongly reinforced at those points from which it is contemplated to do extensive shipping or where much material is to be loaded into the flume over the side. The constant pounding of material being dropped or thrown into the flume and striking on the sides of the V has a tendency to loosen the joints unless strengthened, and sometimes to break down the framework. In order to avoid this danger, it is usually advisable to place the bracket arms or frames and their attendant braces at shorter intervals or distances from each other at such points.

Thus, if in the general flume line construction the arms and braces were placed at a distance of 8 feet apart, at the point where heavy logs or timbers are to be put into the flume it would be good policy to at least double the amount of brackets and braces or place them once in every 4 feet. If the timber to be loaded into the flume at this point were unusually heavy, it might be advisable to reduce the distance between the strengthening arms and braces still more. There are some cases where it has been found necessary to have the arms and braces every 2 feet at those points where the greatest amount of heavy material is loaded into the flume (see Pl. VII, fig. 1). It should

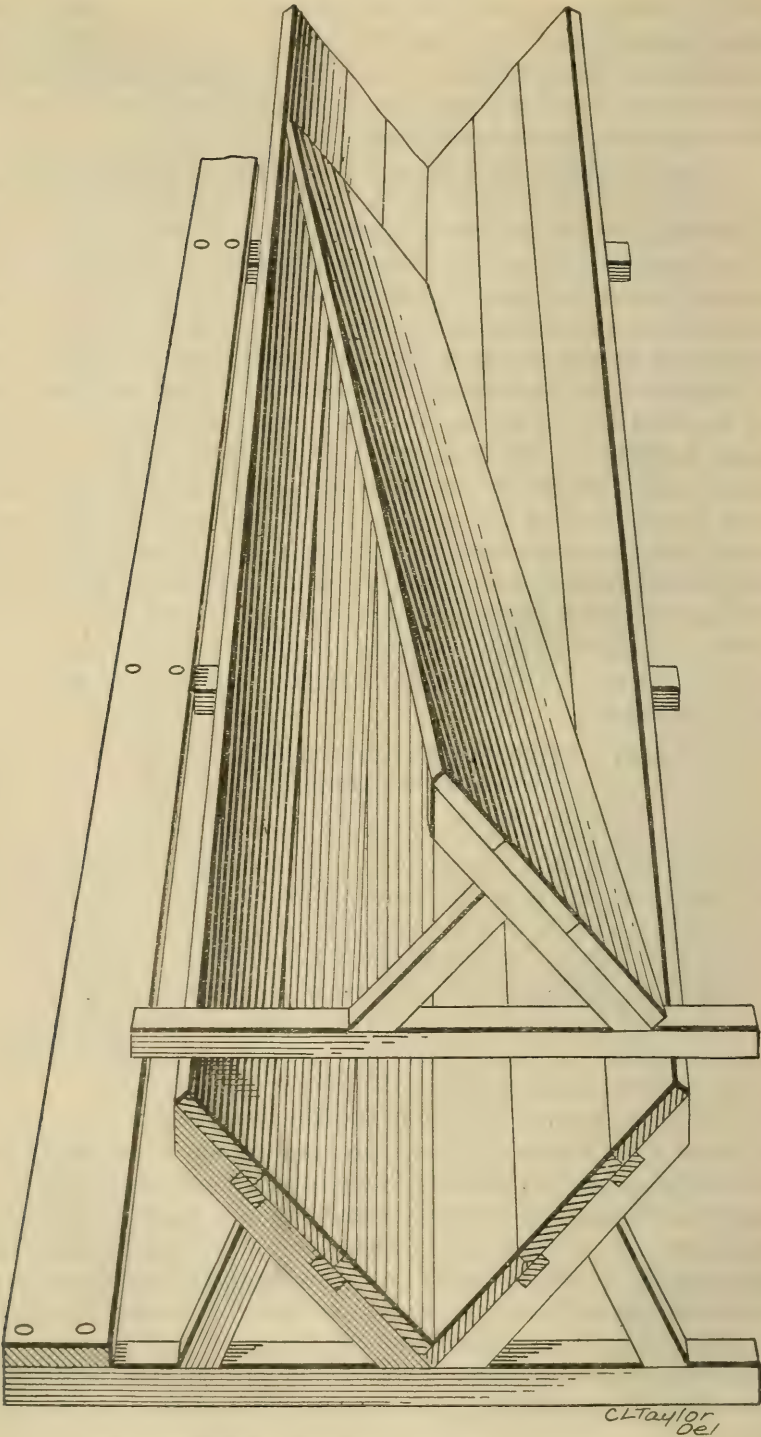
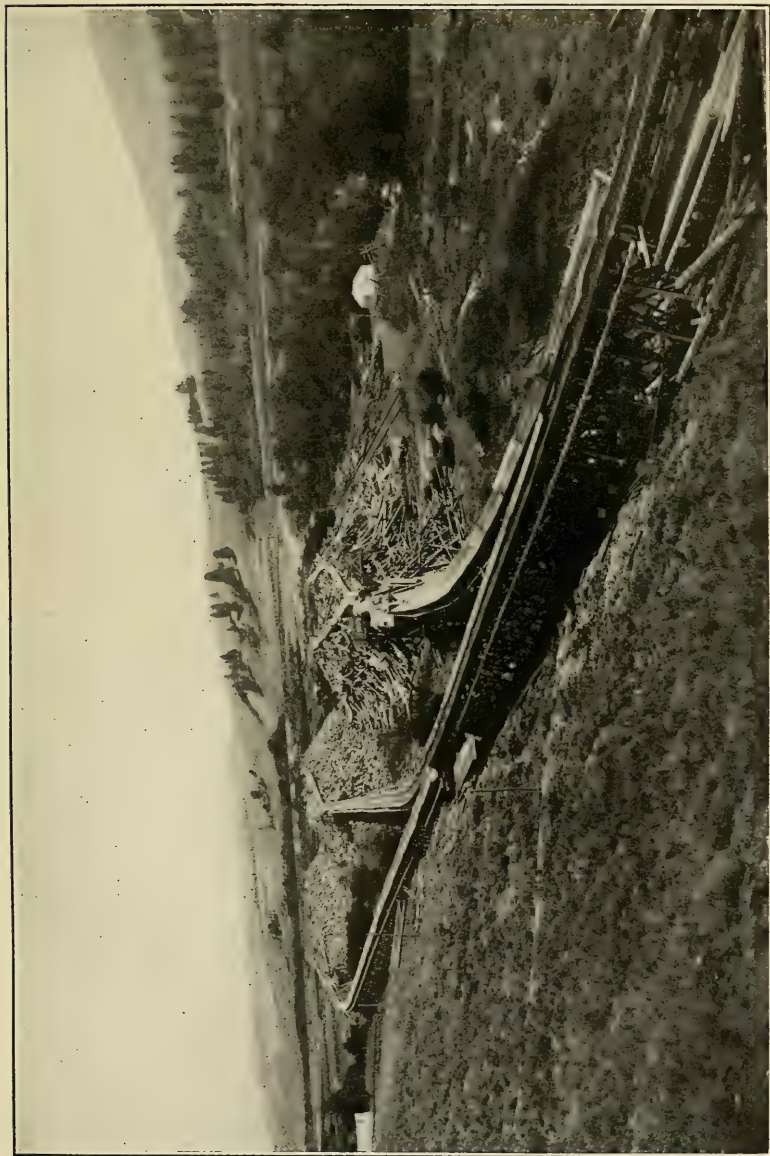


FIG. 6.—A "snub" in position for throwing small material out of a flume.



"Y's" OR SWITCHES AT LOWER END OF A FLUME, SHOWING METHOD OF UNLOADING MATERIAL FROM THE FLUME AT SEVERAL POINTS SO AS TO CAUSE NO INTERFERENCE WITH LOADING OPERATIONS.

In this case the main flume can be switched or thrown quickly from one "Y" to another.



FIG. 1.—A "SNUB" IN OPERATION, THROWING CROSSTIES OUT OF FLUME AT RAILROAD LANDING BY PRESSURE OF WATER.

Man present to prevent material jamming.



FIG. 2.—A "SNUB" WORKING ALONE.



FIG. 1.—BRAILING AND ACCOURTRING LUMBER AT THE UPPER END OF A FLUME.
Note the sloping "ways" on which the brails are slid into the flume after being clamped.



FIG. 2.—A "MINING STULL" DUMP AT THE LOWER END OF A FLUME WHERE THE
STULLS ARE RUN DIRECTLY OUT OF THE "VENT" ENDS.
Note the several "vents" and the railroad spur tracks between the different flume "Y's."



FIG. 1.—A FLUME IN THE CONSTRUCTION OF WHICH SMALL ROUND TIMBER WAS USED FOR EVERYTHING EXCEPT THE "BOX."



FIG. 2.—CRUDE FORM OF FLUME CONSTRUCTION WHERE ONLY THE LINING IS OF SAWED LUMBER, THE REMAINDER BEING CONSTRUCTED OF SMALL ROUND TIMBER AND POLES.

be understood, however, that the necessity for stronger bracing at different points of the flume depends largely, if not entirely, on the class of material being handled, and the prospective operator should be guided by this factor.

TELEPHONES A VALUABLE ADJUNCT TO FLUME OPERATION.

The use of the telephone in connection with fluming operations has been found a very necessary and valuable adjunct by its assistance to the operator in a great many ways. By its use it is possible to know just what is going on at the different points along the flume where "stations" are maintained, and notification of a serious jam or break in the flume can be quickly transmitted to the head of the flume and the shipping of material stopped. Otherwise it might be continued for a considerable length of time or until it was possible to get word to the upper end of the flume, and before this could be accomplished and the shipping stopped the break or block might become of such magnitude that to get the material back and repair the flume would cost almost as much as installing a telephone system. Telephone wires have sometimes been strung along and attached to the sides of flume construction, but this method is not considered generally satisfactory, as there is always the danger that when the flume becomes jammed or is broken down the line may also be put out of commission at the very time when its assistance is most needed. It is generally more advisable to have the telephone wire strung on independent poles or convenient trees where the line runs through a forest than to have it attached to the framework or sides of the flume.

By the use of the telephone it is possible to notify the shipper at the upper end of the flume what class of material to ship, when to ship it, and to keep in touch with what is going on along the flume line at all times. If there be a mill operating at the upper end of the flume, it is often very important that the employees at both ends of the line know exactly what class of material is going to be handled, since for a certain length of time one class might be going to a railroad landing to be loaded onto cars for shipment, after which for the remainder of the day a class of material might be shipped that should be turned by a switch into the storage pile, or vice versa. The valuable aid in fluming operations obtained through the use of the telephone usually makes its installation as an integral part of the plant most advisable.

SAWED MATERIAL FOR STRINGERS, SILLS, BRACES, ETC., NOT A NECESSITY BUT USUALLY MORE ECONOMICAL.

It is not actually necessary that the material used in flume construction, with the exception of the lumber for the "box" or body of the flume, should all be sawed. A number of flumes have been con-

structed and successfully operated where the only sawed lumber used was that for the box, the trestling, sills, crosspieces, stringers, arms, and braces all being made from round poles flattened so as to fit solidly in the construction work. This method of construction is, however, often more expensive than to use the sawed material, where the latter can be economically obtained and cut into proper lengths by a power saw.

The use of poles or small round material usually makes it necessary to cut the braces, arms, etc., into the desired length and form by hand power, and the increased cost of the manual labor necessary in such cases usually more than counterbalances the expense of having the material sawed at a mill, when this can be done without prohibitory expense. Existing conditions should always decide what method of construction will be most advisable. Illustrations of flumes where only the "box" was constructed of sawed lumber are shown in Plate VIII.

WATER USED IN FLUMING SOMETIMES AVAILABLE FOR IRRIGATION PURPOSES.

In some localities in the western country where irrigation is necessary, it will be found possible to utilize the water brought out from the mountains by the aid of a flume for irrigation purposes after it has served its purpose as the transporting medium for logs, timber, or lumber.

Where there is a possibility of using the water for irrigation, it may be found advisable to construct a flume on a larger scale than is absolutely necessary for the simple transportation of the lumber and timber, in order to increase the amount of water available for irrigation purposes. This is a feature that should be carefully considered by the prospective operator when local conditions are such that a combination of the two different uses of the water can be made remunerative.

BRAILING AND ACCOUTRING LUMBER.

Where sawed lumber is being shipped for a long distance in a flume, it has in some cases been found advisable to brail or clamp a number of the boards, planks, or other material together, in order to make a compact body and thus reduce to a minimum the danger of forming jams and injuring the material being transported. It has also been found advisable to accoutre or hitch several of the "brails" together, by the use of short sections of shingle twine, wire, or other form of attachment, between the different clamped or brailed blocks of sawed lumber. In practice it is customary to pile from 10 to 20 boards or planks, usually aggregating about 200 feet, in a block at the mill or point where the shipping is being done. The size of the brail depends on the size of the flume and the class of material being shipped.

A metal clamp of the general form, shown in figure 7, is then slipped over the ends of the brail, and a dry wooden wedge, which can be quickly and cheaply constructed by the use of power saw in the mill, is driven into the end of the brail between the boards or planks, thereby forcing the lumber up against the teeth on the clamp and holding the whole body firmly in the position in which it was placed before being clamped. The twine is attached to the iron clamps on the front and rear ends of the respective brails to be shipped, and when a sufficient number have been prepared they are released in the flume, the weight and momentum of each one tending to keep its fellow, to which it is attached, following it in proper position, and preventing each one from running alongside the other and wedging or piling on the curve. The weight and momentum of the forward brail has a tendency to pull the following brail into line and thus maintain the average momentum of the whole body. This principle can be applied to sawed timbers, using staples and rope or wire to hold them in proper position. Several brails are usually accoutred together by the use of the tarred rope, shingle twine, wire, or other means of attachment.

Upon arrival at the lower end of the flume the wedges are withdrawn, the lumber is released from the brail, and the "clamps" are hauled back to the head of the flume to be used again. This method of consolidating the shipments has been found particularly advisable for use on long, comparatively flat grade flumes, as it reduces very materially the amount of supervision or number of flume walkers necessary to keep the material running from what would be required if it were shipped separately, and prevents the timber from being split, broken, and battered on the ends or otherwise injured as much as when shipped in "loose" board form. Figure 7 shows the method most commonly used in brailing and accoutring material, and a form of clamp.

PLANING MILLS SHOULD BE LOCATED AT LOWER END OF FLUME.

As a general proposition the planing of sawed lumber which it is necessary to transport in a flume should be done only after the fluming process is completed, since fluming lumber after it is planed usually results in more or less discoloration of the surface, which is also liable to be marred in transit, thus injuring its sale value.

SIZE AND CARRYING CAPACITY OF FLUMES FOR DIFFERENT CLASSES OF MATERIAL.

The most advisable size of a flume for successfully transporting different classes of material depends on such factors as the grade, volume of water available, length of flume, etc. The class of material to be handled is always the principal factor to be considered, and

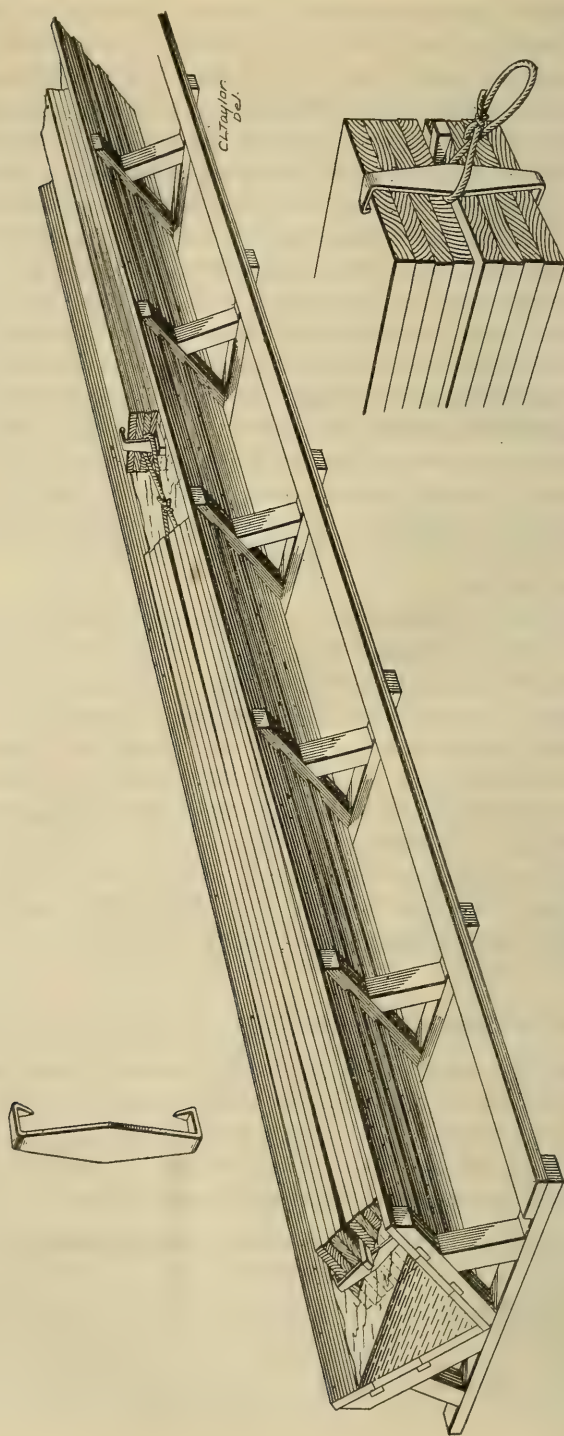


FIG. 7.—Method of clamping and accounting brails of sawed lumber together for shipment.

upon this should depend largely the decision of what type or size of flume should be constructed. The capacity of a 24-inch V-shaped flume 10 miles in length, operated on a grade that was neither very flat nor exceptionally steep, with plenty of water, has been demonstrated as being capable of handling 25,000,000 feet b. m. of railroad crossties and lumber per annum, under especially favorable conditions.

For handling small material, such as railroad crossties, cordwood, mining stulls or props, and loose lumber, a 30-inch V-shaped flume (inside measurement) will usually be found of sufficient capacity for most any requirement, provided the grade is neither too flat nor too steep. Where either of these exceptions obtain, the size of the flume should preferably be increased to 36 to 40 inches.

For a log flume nothing less than a 36-inch V-shaped flume should be built, and a 40 to 60 inch V would be preferable, even for medium-sized logs, if there is a sufficient volume of water available. To operate a log flume successfully and economically there should be a sufficient volume of water available to fill the flume three-fourths full on all moderate grades. It will be apparent that if the grade of a large log flume were very steep, a very large body of water would be required. The larger, longer, and heavier the material to be handled, the larger the size of the V should be, the lesser degree of curvature is permissible, and the stronger must be the construction work.

Tables showing the approximate amount of water in cubic feet required to fill a V-shaped flume on steady grades of different per cents will be found in another portion of this bulletin.

COST OF TRANSPORTING DIFFERENT CLASSES OF MATERIAL.

The cost of transporting material by flumes varies greatly according to the conditions under which the flume is being operated, the class of material, time of year, number of men necessary to operate the flume, and all the other factors that go to make up or reduce the expense of operation. Railroad crossties have been flumed a distance of 20 miles at an actual cost for operation alone of one-half cent per tie, or 15 cents per thousand; sawed lumber in cants of from 2 to 6 inches in thickness at approximately the same rate.

If a flume line is properly constructed on a favorable and steady grade where it can be operated with a plentiful supply of water, the actual cost of transportation alone is very slight after the flume is constructed. But the important fact should not be lost sight of that a flume works only in one direction and that all supplies intended to be used in lumbering operations have to be hauled to the head of the flume by animal or other power.

COST OF CONSTRUCTION.

The cost of constructing flumes will also vary a great deal with the conditions existing in the locality, the cost of lumber, cost of nails, and price of labor. In localities where it is possible to get a boiler, engine, and mill to the upper end of a proposed flume line cheaply and without being compelled to go to the expense of constructing a costly road, where there is plenty of timber easily accessible to the mill, which can be cheaply manufactured into lumber for purposes of construction, with low-priced labor, a flume can be constructed much more economically than in a locality where all these conditions were just the contrary. Rough lumber suitable for the construction of a flume can ordinarily be cut and fitted for construction work at a price varying from \$7.50 to \$10 for manufacture alone, exclusive of stumpage value.

So much depends upon the locality in which a flume is to be constructed, the price of labor, and the facilities for getting the necessary construction material cheaply, that it is impracticable to attempt any very close estimate on the total cost of any flume until all of the surrounding conditions are thoroughly understood. But in general, under favorable conditions, with a basis of \$2.25 per diem for common labor and from \$3.50 to \$4 per diem for carpenters, not including board, suitably prepared lumber should be built into a flume for about \$7.50 per thousand. This would be about the minimum figure, and the cost would be liable to range upward from this price to \$12 or higher, according to the conditions and prices of labor.

The cost of the construction of the Bear Canyon flume in Montana, a 26-inch V 10 miles long, was approximately \$2,000 per mile. The lumber cost \$8.50 per thousand to manufacture and fit it for construction purposes, and it required about 100,000 feet b. m. to the mile. The labor cost \$800 per mile, and \$350 per mile was expended for nails, iron for trusses, and for cost of surveying. This flume was constructed a number of years ago when the cost of material and labor was less than it is to-day.

A flume constructed from Dayton to Woodrock along the Tongue River, in the Bighorn National Forest, Wyo., is said to have cost approximately \$3,500 per mile, in round figures, the cost of different sections varying from \$2,500 to \$7,500 per mile. This was a 30-inch V flume. There was considerable rock work on this line; Granite Canyon had to be passed through, where in some localities the flume was practically pinned to the sides of the canyon walls; there were several rock tunnels to be made through projecting points; and there were necessarily some very high trestles to be constructed. Another difficult feature of the construction of this flume was that of build-

ing the line across several miles of very soft, spongy ground with an almost flat grade to contend with. This flume was also constructed several years ago when the prices of labor and material were not, in general, so high as at the present time.

Probably one of the best examples of modern V-shaped log-flume construction is a flume recently constructed on Rochat Creek, near St. Joe, Idaho. This flume, which is unusually large and strongly constructed for the purpose of handling large, heavy logs, and long timbers, is said to have cost approximately \$8,000 per mile for the 5 miles of its length. This figure includes the cost of construction of a wagon road and telephone line equipment.

DISTANCE BETWEEN BENTS.

There is a decided difference in the opinion of different operators as to the distance that the bents should be placed apart in flume construction, some contending for a 16-foot bent or length of stringers and box on all tangents, while others favor a 12-foot bent. Each has its merits. If a cheap flume for temporary use and medium capacity is desired, then one with 16-foot bents and boxes will usually answer the purpose; that is to say, if the life of the flume is only desired to be from 4 to 6 years. If large material is to be handled and the life of the flume is to be for a long period of time, then the construction work should be stronger and more lasting. If heavy material is to be handled, even the 30-inch V box flume might well be constructed with bents 12 feet apart, and in some cases even less if durability and strength are essential features.

The trouble with the bents 16 feet apart usually is that the stringers are more apt to sag or twist, thereby letting the box sag on one side or the other. This usually causes the water in the flume to slop over at the point of sagging, and the water softens and washes out the foundations under the bents, so that eventually the section of the flume where this occurs becomes uneven in grade and therefore leaky. The result is that the work of repair is much increased and breakdowns in the transportation operations are more frequent. It is usually advisable to place the brackets or arms not more than 4 feet apart on any size or style of flume. When placed farther apart than this it usually permits of too much spring to the box boards, and springing means leaks, which wash out the foundation of the bents and in many kinds of soil, especially on side hills, causes expensive slides or washouts.

The same general principle applies in connection with the lining of a box, and there is much difference of opinion on the value of the different types of construction. It is contended by some operators that the 1½-inch box lining, strengthened with 1 by 4 inch battens

firmly nailed over the joints on the outside, is much more satisfactory than the doubled 1-inch boards. It is contended that the 1-inch doubled box is not as rigid as the 1½-inch lining reinforced by the battens, and that the doubled box permits of a constant spring when heavy timber is passing through the flume. This causes the boards gradually to work apart and fill in between the two courses with bark and sediment, eventually causing the box to leak badly.

Another contention is that in relining there is never a good solid foundation to nail to, and that the nails keep working loose and catching passing timber, causing jams. It is claimed that, by the use of the 1½-inch or 2-inch box lining reinforced by the battens nailed on from the outside, the element of "spring" is materially reduced.

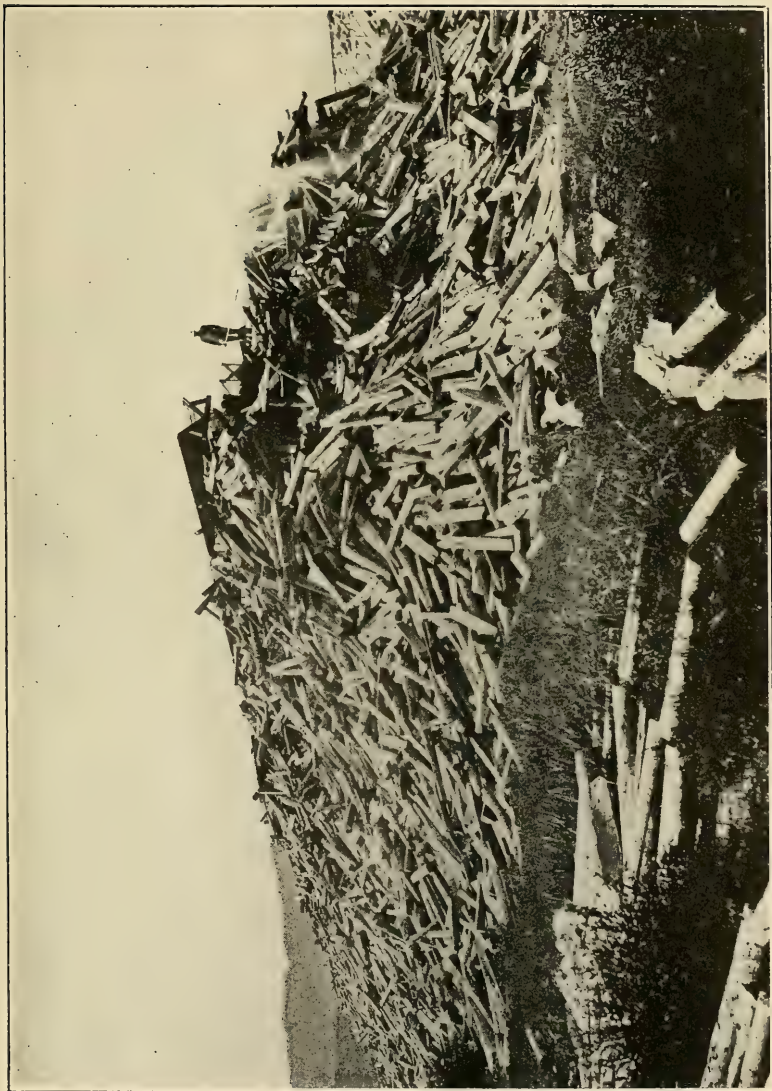
ADVISABLE METHOD OF NAILING.

In the construction of either type of box or the nailing on of the battens, the nails should, whenever possible, be driven from the outside and clinched on the inside of the box with the point of the nail turned *down* the flume. By so doing the nails become tighter as the inside of the box wears, since the flumed material strikes the nails and drives or draws them in harder. When the inside of the box is so badly worn that it is necessary to replace the lining, the new lining furnishes a solid substance through which to nail. Each style of construction has its particular merits, and the prospective operator should decide for himself which is more applicable to his needs.

Tables showing approximate amount of material necessary to construct flumes of different sizes follow:

TABLE 1.—Weight of water in a 16-foot section of flume when filled to various depths.

Slant depth.		Slant depth.		Slant depth.	
Weight of water in a section of flume 16 feet long.		Weight of water in a section of flume 16 feet long.		Weight of water in a section of flume 16 feet long.	
<i>Inches.</i>	<i>Pounds.</i>	<i>Inches.</i>	<i>Pounds.</i>	<i>Inches.</i>	<i>Pounds.</i>
20	1,390	34	4,010	48	7,990
22	1,680	36	4,490	50	8,670
24	2,000	38	5,010	52	9,360
26	2,350	40	5,540	54	10,100
28	2,710	42	6,110	56	10,900
30	3,110	44	6,740	58	11,700
32	3,560	46	7,300	60	12,500



END DUMP OF A FLUME LINE.

In this case the line was extended as necessity required, using the shipped material as the foundation for the extension.

TABLE 2.—Amount of water required to fill flumes to various depths at different grades.

Slant depth (inches).	Grade—per cent.															
	1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
	Flow—Cubic feet per second.															
20.....	10	14	17	19	22	24	26	28	29	31	32	34	36	39	41	43
22.....	13	18	22	25	28	31	33	36	38	40	42	44	47	51	54	56
24.....	16	23	28	32	36	39	42	45	48	51	53	55	60	64	68	71
26.....	20	28	34	40	45	49	53	56	60	63	66	69	74	79	81	89
28.....	24	34	42	48	54	59	64	68	72	76	80	84	90	96	102	108
30.....	29	41	50	58	65	71	77	82	87	92	96	101	109	116	123	130
32.....	35	49	60	69	78	85	92	98	104	109	115	120	130	138	147	155
34.....	41	58	71	81	91	100	108	116	122	129	136	142	153	163	173	183
36.....	48	67	82	95	107	117	126	135	143	150	158	165	178	190	202	212
38.....	55	78	95	110	123	135	145	156	165	174	182	190	206	220	233	245
40.....	63	89	109	125	140	154	166	178	189	199	209	218	235	251	266	281
42.....	72	101	127	143	160	175	189	203	215	226	237	248	267	286	304	319
44.....	81	114	140	163	181	199	214	229	243	257	269	281	303	325	344	362
46.....	91	130	158	183	204	223	241	258	274	289	302	316	341	365	387	408
48.....	102	144	177	205	230	251	271	290	307	323	340	354	383	410	434	458
50.....	115	161	198	228	255	279	302	323	343	360	378	397	428	456	483	510
52.....	127	179	219	253	283	311	336	358	381	401	420	440	475	507	537	567
54.....	140	198	242	281	313	342	371	396	421	443	465	484	524	560	594	626
56.....	156	220	269	311	348	383	412	440	467	492	517	538	583	621	661	697
58.....	170	241	295	339	380	415	449	481	510	537	564	589	636	681	721	759
60.....	186	262	322	372	415	455	492	525	558	589	616	644	695	744	788	831

TABLE 3.—Velocity of water in flumes when filled to various depths at different grades.

Slant depth (inches).	Grade—per cent.															
	1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20
	Velocity of water—Miles per hour.															
20.....	5	7	8	9	11	12	13	13	14	15	15	16	17	18	19	21
22.....	5	7	9	10	11	13	14	14	15	16	17	18	19	20	21	23
24.....	5	8	9	11	12	13	14	15	16	17	18	19	20	22	23	24
26.....	5	8	10	12	13	14	15	16	17	18	19	20	22	23	24	26
28.....	6	9	10	12	14	15	16	17	18	19	20	21	23	24	26	27
30.....	6	9	11	13	14	16	17	18	19	20	21	22	24	25	27	29
32.....	7	9	11	13	15	16	18	19	20	21	22	23	25	27	28	30
34.....	7	10	12	14	15	17	18	20	21	22	23	24	26	28	29	31
36.....	7	10	12	14	16	18	19	20	22	23	24	25	27	29	31	32
38.....	7	11	13	15	17	18	20	21	22	24	25	26	28	30	32	33
40.....	8	11	13	15	17	19	20	22	23	24	26	27	29	31	33	35
42.....	8	11	14	16	18	20	21	23	24	25	26	28	30	32	34	36
44.....	8	12	14	16	18	20	22	23	25	26	27	29	31	33	35	37
46.....	8	12	15	17	19	21	22	24	25	27	28	29	32	34	36	38
48.....	9	12	15	17	20	21	23	25	26	28	29	30	33	35	37	39
50.....	9	13	16	18	20	22	24	25	27	28	30	31	34	36	38	40
52.....	9	13	16	18	21	23	24	26	28	29	31	32	35	37	39	41
54.....	9	13	16	19	21	23	25	27	28	30	31	33	35	38	40	42
56.....	10	14	17	19	22	24	26	28	29	31	32	34	36	39	41	43
58.....	10	14	17	20	22	24	26	28	30	31	33	34	37	40	42	44
60.....	10	14	18	20	23	25	27	29	30	32	34	35	38	41	43	45

In the preparation of these tables the formula $v = c\sqrt{rs}$ was used, in which v = the velocity of the water in feet per second, c = a constant, r = the hydraulic radius in feet, and s = the slope. Each step was carried out to three significant figures. The following values for c and r were used:

Slant depth.	c	r	Slant depth.	c	r	Slant depth.	c	r
<i>Inches.</i>			<i>Inches.</i>			<i>Inches.</i>		
20	108	0.417	34	121	0.708	48	128	1.00
22	111	.458	36	122	.750	50	129	1.04
24	113	.500	38	123	.792	52	130	1.08
26	115	.542	40	124	.833	54	131	1.12
28	116	.583	42	125	.875	56	132	1.17
30	118	.625	44	126	.917	58	132	1.21
32	119	.667	46	127	.958	60	133	1.25

This formula is based upon experiments with slopes of less than 10 per cent, and while its application to steeper grades has not been thoroughly checked by actual determinations of velocity, the results are considered sufficiently accurate for use in the design of timber flumes.

TABLE 4.—*Estimate of approximate amount of material required for construction of flumes.*

26-INCH "V" FLUME WITH 1½-INCH BATTENED BOX.

Kinds of lumber.	Lumber required per mile.								Nails required per mile.		
	Dimensions.		Feet to piece.	Pieces to each box.	Feet to each box.	Pieces per mile.	Boxes per mile.	Feet b. m. per mile.	Size.	Pounds.	Kegs.
	Size.	Length.									
	<i>Inches.</i>	<i>Ft. in.</i>	<i>Ft. in.</i>		<i>Ft. in.</i>						
Mud sills.....	4 x 4	7 3	9 8	1	9 8	330	330	3,190	10-penny..	763	7½
Posts.....	4 x 4	7 3	9 8	2	19 4	660	330	6,380	12-penny..	682	6¾
Caps.....	4 x 4	3 6	4 8	1	4 8	330	330	1,540	16-penny..	113	1
Braces, sway...	1 x 6	9 0	4 6	2	9 0	660	330	2,970	20-penny..	425	4½
Braces, lateral..	1 x 6	7 6	3 9	4	15 0	1,100	1,275	14,125	One keg of 40-penny nails and 1 keg of 60-penny nails should usually be allowed for such preliminary work as bridging, etc.		
Stringers.....	4 x 6	16 0	32 0	2	64 0	660	330	21,120			
Sills.....	2½ x 4	4 6	3 9	3	11 3	990	330	3,713			
Braces.....	2½ x 4	0 11	0 10	6	5 0	1,980	330	1,650			
Arms.....	2½ x 4	2 2	1 9½	6	10 10	1,980	330	3,575			
Box boards.....	1½ x 54	16 0	(2)	-----	108 0	-----	330	35,640			
Battens.....	1 x 4	5 0	1 8	12	20 0	3,960	330	6,600			
Running boards	1½ x 10	16 0	20 0	1	20 0	330	330	6,600			
Add for waste..								97,103 2,897			
Total.....								100,000	Total....	1,983	19½

¹ Lateral braces are only figured for five-sixths of a mile, as at least one-sixth of each mile, on an average, will be too close to the ground to require the use of these braces.

² Various sizes.

TABLE 4.—*Estimate of approximate amount of material required for construction of flumes—Continued.*

30-INCH "V" FLUME WITH 1-INCH DOUBLE BOX.

Kinds of lum- ber.	Lumber required per mile.								Nails required per mile.		
	Dimensions.		Feet to piece.	Pieces to each box.	Feet to each box.	Pieces per mile.	Boxes per mile.	Feet b. m. per mile.	Size.	Pounds.	Kegs.
	Size.	Length.									
	<i>Inches.</i>	<i>Ft. in.</i>	<i>Ft. in.</i>		<i>Ft. in.</i>						
Mud sills.....	4 x 6	7 8	15 4	1	15 4	330	330	5,060	10-penny..	500	5
Posts.....	4 x 6	7 3	14 6	2	29 0	660	330	9,570	12-penny..	528	5½
Caps.....	4 x 6	4 7	9 2	1	9 2	330	330	3,025	16-penny..	948	9½
Braces, sway.....	1 x 6	9 2	4 7	2	9 2	660	330	3,025	20-penny..	156	1½
Braces, lateral.....	1 x 6	7 6	3 9	4	15 0	1,100	1 275	14,125	One keg of 40-penny nails and one keg of 60-penny nails should usually be allowed for such preliminary work as bridging, etc.		
Stringers.....	4 x 8	16 0	42 8	2	85 4	660	330	28,160			
Sills.....	2½ x 5	5 4	5 6½	3	16 8	990	330	5,500			
Braces.....	2½ x 5	1 1	1 1½	6	6 9	1,980	330	2,228			
Arms.....	2½ x 5	2 6	2 7½	6	15 7½	1,980	330	5,157			
Box boards.....	2 x 62	16 0	(2)	-----	165 4	-----	330	54,560			
Running boards	1½ x 10	16 0	20 0	1	20 0	330	330	6,600			
Add for waste..	-----	-----	-----	-----	-----	-----	-----	127,010 7,990			
Total.....	-----	-----	-----	-----	-----	-----	-----	135,000	Total....	2,132	21¼

30-INCH "V" FLUME WITH 1½-INCH BATTENED BOX.

Mud sills.....	4 x 6	7 8	15 4	1	15 4	330	330	5,060	10-penny..	763	7½
Posts.....	4 x 6	7 3	14 6	2	29 0	660	330	9,570	12-penny..	780	7¾
Caps.....	4 x 6	4 7	9 2	1	9 2	330	330	3,025	16-penny..	113	1
Braces, sway...	1 x 6	9 2	4 7	2	9 2	660	330	3,025	20-penny..	425	4½
Braces, lateral..	1 x 6	7 6	3 9	4	15 0	1,100	1 275	14,125	One keg of 40-penny nails and 1 keg of 60-penny nails should usually be allowed for such preliminary work as bridging, etc.		
Stringers.....	4 x 8	16 0	42 8	2	85 4	660	330	28,160			
Sills.....	2½ x 5	5 4	5 6½	3	16 8	990	330	5,500			
Braces.....	2½ x 5	1 1	1 1½	6	6 9	1,980	330	2,228			
Arms.....	2½ x 5	2 6	2 7½	6	15 7½	1,980	330	5,157			
Box boards.....	1½ x 62	16 0	(?)	-----	124 0	-----	330	40,920			
Battens.....	1 x 4	5 0	1 8	12	20 0	3,960	330	6,600			
Running boards	1½ x 10	16 0	20 0	1	20 0	330	330	6,600			
Add for waste..	-----	-----	-----	-----	-----	-----	-----	119,970			
Total.....	-----	-----	-----	-----	-----	-----	-----	125,000	Total....	2,091	20¼

36-INCH "V" FLUME WITH 1½-INCH BATTENED BOX.

Mud sills.....	4 x 6	8 6	17 0	1	17 0	440	440	7,480	10-penny..	1,300	13
Posts.....	4 x 6	7 3	14 6	2	29 0	880	440	12,760	12-penny..	396	4
Caps.....	4 x 6	5 0	10 0	1	10 0	440	440	4,400	16-penny..	1,075	10½
Braces, sway...	1 x 6	10 0	5 0	2	10 0	880	440	4,400	20-penny..	447	4½
Braces, lateral..	1 x 6	7 6	3 9	4	15 0	1,467	1 366½	15,500	One keg of 40-penny nails and one keg of 60-penny nails should usually be allowed for such preliminary work as bridging, etc.		
Stringers.....	4 x 8	12 0	32 0	2	64 0	880	440	28,160			
Sills.....	3 x 5	6 0	7 6	3	22 6	1,320	440	9,900			
Braces.....	3 x 5	1 5	1 9½	6	10 7½	2,640	440	4,675			
Arms.....	3 x 5	3 0	3 9	6	22 6	2,640	440	9,900			
Box boards.....	1½ x 74	12 0	(?)	-----	111 0	-----	440	48,840			
Battens.....	1 x 4	4 0	1 4	18	24 0	7,920	440	10,560			
Running boards	1½ x 10	12 0	15 0	1	15 0	440	440	6,600			
Add for waste..	-----	-----	-----	-----	-----	-----	-----	153,175			
Total.....	-----	-----	-----	-----	-----	-----	-----	160,000	Total....	3,218	32¼

¹ Lateral braces are only figured for five-sixths of a mile, as at least one-sixth of each mile, on an average, will be too close to the ground to require the use of these braces.

² Various sizes.

TABLE 4.—*Estimate of approximate amount of material required for construction of flumes—Continued.*

54-INCH "V" FLUME WITH 2-INCH BATTENED BOX.

Kinds of lumber.	Lumber required per mile.								Nails required per mile.		
	Dimensions.		Feet to piece.	Pieces to each box.	Feet to each box.	Pieces per mile.	Boxes per mile.	Feet b. m. per mile.	Size.	Pounds.	Kegs.
	Size.	Length.									
	<i>Inches.</i>	<i>Ft. in.</i>	<i>Ft. in.</i>		<i>Ft. in.</i>						
Mud sills.....	6 x 6	10 0	30 0	1	30 0	440	440	13,200	12-penny..	1,700	17
Posts.....	6 x 6	7 3	21 9	2	43 6	880	440	19,140	16-penny..	1,075	10½
Caps.....	6 x 6	7 0	21 0	1	21 0	440	440	9,240	20-penny..	390	4
Braces, sway...	1½ x 6	11 0	8 3	2	16 6	880	440	7,260	40-penny..	3,625	36½
Braces, lateral..	1½ x 6	7 6	5 7½	4	22 6	1,467	1,366½	8,250	One keg of 40-penny nails and one keg of 60-penny nails should usually be allowed for such preliminary work as bridging, etc.		
Stringers.....	6 x 8	12 0	48 0	2	96 0	880	440	42,240			
Sills.....	4 x 6	7 0	14 0	3	42 0	1,320	440	18,480			
Braces.....	4 x 6	1 9½	3 7	6	21 6	2,640	440	9,460			
Arms.....	4 x 6	4 6	9 0	6	54 0	2,640	440	23,760			
Box boards.....	2 x 110	12 0	(?)		220 0		440	96,800			
Battens.....	1½ x 4	4 0	1 8	24	40 0	10,560	440	17,600			
Running boards	2 x 12	12 0	24 0	1	24 0	440	440	10,560			
Add for waste..								275,990			
								9,010			
Total.....								285,000	Total....	6,790	68

¹ Lateral braces are only figured for five-sixths of a mile, as at least one-sixth of each mile, on an average, will be too close to the ground to require the use of these braces.

² Various sizes.



BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 88



Contribution from the Bureau of Entomology, L. O. Howard, Chief.
April 30, 1914.

THE CONTROL OF THE CODLING MOTH IN THE PECOS VALLEY IN NEW MEXICO.

By A. L. QUAINANCE, *in Charge of Deciduous Fruit Insect Investigations.*

INTRODUCTION.

For some years complaints have been received by the Bureau of Entomology from the fruit growers in the Pecos Valley, N. Mex., of the severe injury to apples and pears by the codling moth (*Carpocapsa pomonella* L.). The methods employed in the control of this insect in other apple-growing regions have, in the Pecos Valley, been stated to be there much less efficient, so that a considerable portion of the crop of fruit has been wormy and unsalable.

The codling moth should yield as readily to treatment in the Pecos Valley as elsewhere, though, owing to favorable climatic conditions, it was surmised that it might develop an additional generation. It was not believed, however, that the behavior of the insect in that region was essentially different from its behavior in other sections, and the lack of satisfactory results from spraying operations, it was thought, probably resulted from failure to accomplish this work in a thorough and timely manner.

Beginning in the spring of 1912 an investigation of the codling moth was undertaken by the Bureau of Entomology, with headquarters at Roswell, N. Mex., and Mr. A. G. Hammar, who had had much experience with this insect at other field stations of the bureau, was assigned to the work. During that year he was assisted by Mr. Earl R. Van Leeuwen, and during 1913 by Mr. L. L. Scott and Mr. E. W. Geyer. Owing to the unfortunate death of Mr. Hammar there devolves upon the writer the necessity of preparing for publication, for the benefit of the Pecos Valley fruit growers, the results of Mr. Hammar's experiments. The investigations carried out by Mr. Hammar comprise a thorough inquiry into the life history and habits of the codling moth in that region, and experiments with sprays in orchards. The results of the life-history studies will be given in another paper.

NOTE.—This bulletin describes the codling moth as it affects fruit growing in the Pecos Valley, N. Mex. It is of interest to fruit growers in the Southwest.

The present article deals with results obtained in spraying in 1913. Work was carried out in two orchards, namely, that of Messrs. Sherman & Johnson and that of Mr. Robert Beers. Unfortunately the report of results in the latter orchard is not entirely complete, so that the details of these experiments can not be given. In general, however, the results obtained in the Beers orchard agree with those secured in the Sherman & Johnson orchard, and the latter are given in detail in the following pages.

EXPERIMENTS IN THE SHERMAN & JOHNSON ORCHARD.

A portion of the Sherman & Johnson orchard, about 5 acres in extent, was selected for spraying experiments and was subdivided into plats, as shown in figure 1.

The trees were large, and codling-moth conditions were fairly typical for the valley. Plat I received three applications; Plat II, four applications; and Plat III, five applications of arsenate of lead spray. Plat IV was left unsprayed throughout the season for purposes of comparison. A good power sprayer was used, capable of supplying three or four leads of hose, and maintaining a pressure of 200 to 225 pounds. (See fig. 2, showing outfit in operation, and size of trees used.) Further information concerning the treatments and the dates of spray applications for the respective plats is given in Table I.

TABLE I.—*Treatments and dates of applications of sprays for codling moth, Sherman & Johnson orchard, Roswell, N. Mex., 1913.*

Dates of applications.	Plat I (3 applications).	Plat II (4 applications).	Plat III (5 applications).	Plat IV (unsprayed).
Apr. 24-25..... (After falling of petals.)	Arsenate of lead, 6 pounds to 200 gallons of water. Bordeaux nozzles. 16½ gallons per tree. 225 pounds pressure.	Arsenate of lead, 6 pounds to 200 gallons of water. Bordeaux nozzles. 16½ gallons per tree. 225 pounds pressure.	Arsenate of lead, 6 pounds to 200 gallons of water. Bordeaux nozzles. 16½ gallons per tree. 225 pounds pressure.	Unsprayed.
May 7-8.....	Arsenate of lead, 8 pounds to 200 gallons of water. Vermorel type nozzles. 13½ gallons per tree. 200 pounds pressure.	Arsenate of lead, 8 pounds to 200 gallons of water. Vermorel type nozzles. 13½ gallons per tree. 200 pounds pressure.	Arsenate of lead, 8 pounds to 200 gallons of water. Vermorel type nozzles. 13½ gallons per tree. 200 pounds pressure.	Do.
June 16-17.....	Arsenate of lead, 8 pounds to 200 gallons of water. Vermorel type nozzles. 15½ gallons per tree.	Arsenate of lead, 8 pounds to 200 gallons of water. Vermorel type nozzles. 15½ gallons per tree.	Arsenate of lead, 8 pounds to 200 gallons of water. Vermorel type nozzles. 15½ gallons per tree.	Do.
July 14-15.....		Arsenate of lead, 8 pounds to 200 gallons of water. Vermorel type nozzles. 17½ gallons per tree.	Arsenate of lead, 8 pounds to 200 gallons of water. Vermorel type nozzles. 17½ gallons per tree.	Do.
Aug. 2.....			Arsenate of lead, 8 pounds to 200 gallons of water. Vermorel type nozzles. 9½ gallons per tree.	Do.

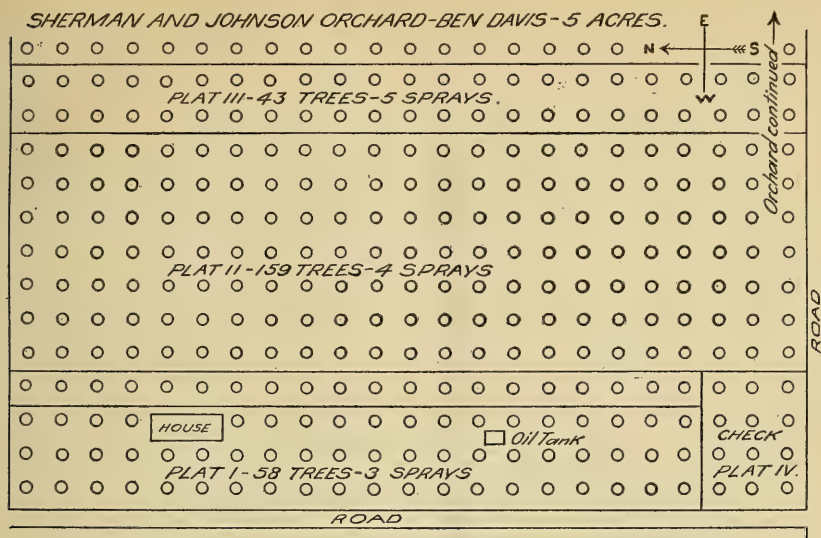


FIG. 1.—Diagram showing arrangement of trees used in codling-moth experiments, Sherman & Johnson orchard, Roswell, N. Mex. (Original.)



FIG. 2.—View in Sherman & Johnson orchard, Roswell, N. Mex., showing size of trees and power sprayer in operation. (Original.)

It will be noted from Table I that the amount of spray used in all applications was large, and probably considerably in excess of that used by the average fruit grower in the valley. The amount of spray applied immediately following the falling of the petals (April 24-25) exceeded somewhat the amount given in any subsequent application. It will be noted also that Bordeaux nozzles were used at this time, whereas in subsequent treatments the so-called eddy chamber or Vermorel type of nozzle was used, producing a fine cone-shaped spray.

In Table II are shown the number and percentage of sound fruit from each of five trees of each plat, as well as the total number and total percentage of sound and wormy fruit for the five trees of the respective plats.

TABLE II.—*Number of sound and wormy apples from each tree of each plat, Sherman & Johnson orchard, Roswell, N. Mex., 1913.*

Plat and condition of fruit.	Tree 1.	Tree 2.	Tree 3.	Tree 4.	Tree 5.	Total fruit for plat.	Total per cent sound fruit.
Plat I.							
Wormy.....	138	144	153	179	152	766	
Sound.....	2,918	2,022	3,382	3,418	3,239	14,979	
Total.....	3,056	2,166	3,535	3,597	3,391	15,745	
Per cent sound.....	95.48	93.35	95.67	95.02	95.52	.....	95.13
Plat II.							
Wormy.....	86	39	33	37	70	265	
Sound.....	4,271	4,086	3,378	3,344	5,504	20,583	
Total.....	4,357	4,125	3,411	3,381	5,574	20,848	
Per cent sound.....	98.02	99.05	99.03	98.90	98.74	.....	98.72
Plat III.							
Wormy.....	51	18	40	25	14	148	
Sound.....	6,283	4,479	4,494	4,618	4,442	24,316	
Total.....	6,334	4,497	4,534	4,643	4,456	24,464	
Per cent sound.....	99.19	99.59	99.12	99.46	99.68	.....	99.39
Plat IV.							
Wormy.....	5,308	2,671	3,813	3,486	3,336	18,614	
Sound.....	2,871	2,349	2,873	2,765	1,958	12,816	
Total.....	8,179	5,020	6,686	6,251	5,294	31,430	
Per cent sound.....	35.12	46.79	42.97	44.23	37.03	.....	40.77

It will be seen that Plat I, which received a total of three applications of an arsenate of lead spray, gave 95.13 per cent sound fruit. Plat II, with four applications, yielded a somewhat higher quantity of sound fruit, namely, 98.72 per cent; while from Plat III, which received five spray applications, 99.39 per cent of the fruit for the season was sound. Plat IV, which was not sprayed during the season, shows only 40.77 per cent of the fruit free from codling moth injury. In determining these results, examinations were made as to worminess of all the apples produced on the five count trees throughout the season; that is, the fruit which fell, the fruit which was picked from the trees in thinning, and that picked at harvest time.

It would appear that with the minimum of three applications, made as shown in Table I, injury from the codling moth in the Pecos Valley may be reduced to less than 5 per cent of the total crop of apples produced. For each of the two additional applications an increase in sound fruit is shown, but probably not in proportion to the expense involved. It should be borne in mind, however, that in these experiments applications were made with much thoroughness, and unless the orchardist will do equally as thorough work it will be better for him to make the additional applications.

PLACES OF ENTRANCE OF FRUIT BY CODLING MOTH LARVÆ.

Many observations in different parts of the country have shown that the majority of codling moth larvæ normally enter the apple at



FIG. 3.—Showing condition of calyx lobes of Ben Davis apple: *a*, Two days after falling of petals; *b*, ten days after falling of petals. (Original.)

the calyx end. A careful study of the places of entering sprayed fruit by larvæ, whether at calyx, side, or stem, throws much light on the relative effectiveness of the respective spray applications. All experiments corroborate the statement that the treatment given immediately after the falling of the petals is by far the most important one and that its omission can not be corrected by subsequent treatments, however thoroughly made.

A study of the behavior of the calyx lobes of the recently set apples in the Roswell section furnishes evidence of value in timing spray applications. Ordinarily in the East there is a period of about 10 days following the dropping of apple blossoms during which the

calyx lobes remain open, so that the spray may be successfully directed into the calyx cups. In New Mexico, however, it would appear that the calyx lobes of the little apples do not draw together nearly so quickly after the falling of the petals and may remain open in suitable condition for calyx spraying for a period of from two to three weeks, varying somewhat with the variety and season. (Figs. 3 and 4.)

This condition renders it possible to apply the second spray in a way to supplement the first spray into the calyx cups.

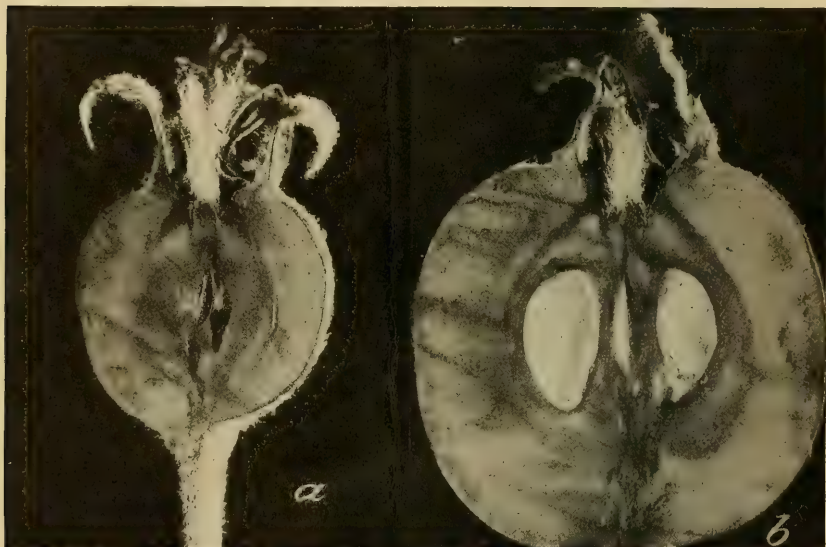


FIG. 4.—Showing condition of calyx lobes of Ben Davis apple: *a*, 18 days after falling of petals; *b*, 30 days after falling of petals. (Original.)

The effect of spraying in changing the relative proportion of larvæ which succeed in entering the fruit at the calyx, side, and stem is shown for Plats I to III in Table III. The normal behavior of the larvæ in entering the fruit may be seen by referring to the figures for Plat IV of this table. It will be noted that on the unsprayed plat somewhat over one-half (53.72 per cent) of the total larvæ for the season entered the fruit at the calyx end.

TABLE III.—Number and percentage of codling moth larvæ entering fruit at calyx, side, and stem for Plats I-IV, Sherman & Johnson orchard, Roswell, N. Mex., 1913.

Total larvæ for plat for season entering at—	Plat I.	Per cent.	Plat II.	Per cent.	Plat III.	Per cent.	Plat IV.	Per cent.
Calyx.....	19	2.31	17	6.27	10	6.76	12,663	53.72
Side.....	789	96.45	249	91.88	128	86.48	9,622	40.82
Stem.....	10	1.24	5	1.85	10	6.76	1,285	5.46
Total.....	818	100.00	271	100.00	148	100.00	23,570	100.00

This table also shows the destructive influence of sprays in lessening the actual number of larvæ. Thus on Plat I, which received three sprays, there was a total of 818 larvæ for the season, on the five count trees; on Plat II, which received four sprays, the number of larvæ for the five trees was 271; while on Plat III, which received five sprays, only 148 codling moth larvæ were found in fruit from the five "count trees" during the year. The foregoing figures are in marked contrast with the total number of larvæ found in fruit from the five unsprayed trees, namely, 23,570.

RECOMMENDATIONS BASED ON THE FOREGOING RESULTS.

While the results reported herewith are very clear-cut, the bureau would not be warranted in formulating definite recommendations based upon the work thus far carried out in the Pecos Valley were it not for the reason that these results substantiate the results obtained from a large series of spraying experiments against the codling moth in many parts of the United States. In Table I, showing treatments and dates of applications, the reader will note that the first applications were made with Bordeaux nozzles and the later applications with eddy chamber nozzles. Entomologists of certain Western States who have experimented with the codling moth under arid conditions insist upon the advantage of a coarse spray given at the time immediately following the dropping of the petals. Tests of the comparative value of coarse and fine sprays under eastern conditions show that there is apparently but little difference as regards the effectiveness in the control of the insect of a coarse and fine spray. The Roswell experiments did not include a comparison of coarse and fine sprays and no specific information can be furnished on this point, and it would appear safer for the orchardist to follow the methods used by Mr. Hammar until further information is obtained. It will also be noted that spraying was done under high pump pressure. This should not be construed to mean that effective work in the control of the codling moth can not be accomplished except by use of power outfits working at high pressure. Very good results have been obtained from the use of barrel sprayers working at perhaps 100 to 120 pounds pressure.

The prime essential in the control of the codling moth is that the treatment given immediately after the falling of the blossoms shall be made with great thoroughness, in order to insure the lodgment of poison in the calyx cup of each and every apple. This result is best secured by so handling the spray rods that the spray is directed downward into the upright clusters of the little apples. This spraying especially should be made rather deliberately and with great pains. Frequent examination of sprayed trees should be made to determine how thoroughly calyx cups are being filled with poison.

First application.—As soon as the petals have fallen, spray the trees with arsenate of lead, using the poison at the rate of 6 pounds to 200 gallons of water. Direct the spray straight into the calyx cups, for which purpose an elbow or crook should be used on the end of the spray rods. In spraying high trees a tower is indispensable, as shown in figure 2.

Second application.—About two weeks after the falling of the petals spray with arsenate of lead at the rate of 8 pounds to 200 gallons of water. Make an effort to apply this spray before the calyx lobes are more than three-fourths closed, which may be determined by careful examination in the orchard. (See fig. 3.) Direct this spray, also, as much as possible straight into the calyx cups, and at the same time take care to coat the leaves and fruit.

Third application.—Eight or nine weeks after the falling of the petals spray again with arsenate of lead at the rate of 8 pounds to 200 gallons of water. In this treatment cover the foliage and fruit as uniformly as possible with the poison.

Subsequent applications.—The three applications specified, if thoroughly made, should effectively control the codling moth, as shown by the results of experiments herewith reported. If these applications have not been thoroughly made, and it is seen that the codling moth will do considerable injury, additional applications will doubtless be desirable to check the insect as much as possible. Thorough work, especially in applying the first and second applications, should largely obviate the necessity for more than three treatments.

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(PROFESSIONAL PAPER.)

THE DEATH OF CHESTNUTS AND OAKS DUE TO ARMILLARIA MELLEA.

By W. H. LONG,

Forest Pathologist, Office of Investigations in Forest Pathology.

INTRODUCTION.

Some time ago complaint was made to the Office of Investigations in Forest Pathology that the chestnut trees on certain areas near New Berlin, in Chenango County, N. Y., were rapidly deteriorating; that some were dead, others dying, and the remainder in poor health. Since this region is not in the known range of the chestnut bark disease (*Endothia parasitica*), the dying of the chestnut could not be attributed to this fungus, and the writer was therefore detailed to make an investigation of the trouble.

CHARACTER OF THE TIMBER EXAMINED.

Two areas of woodland of about 20 acres each were examined. The timber consisted of a mixed stand of chestnut, oak, and white pine, with a sprinkling of poplar, maple, and hemlock. All of the timber above a diameter of 6 inches, or even less, was being cut. Much of it had only recently been felled, while some was still uncut. The oak and chestnut were being made into railroad ties and the pine into lumber. Both tracts of timber were located on the level tops and slopes of rather rough ridges. The average age of the chestnut and oak was from 60 to 100 years. One of the areas had been partially logged over 20 years ago; the other had never been logged. There have been no forest fires in either tract, so far as known. As the two areas were close to each other and similarly located, they will be treated as a whole in this discussion.

CHARACTER OF DATA OBTAINED.

In addition to the felled trees of chestnut and oak, dead, dying, and badly diseased standing trees were studied. No attempt was made, on account of limited time, to examine the roots of any number

NOTE.—A record of the results of field investigations of the condition of chestnut and oak in Chenango County, N. Y.

of living trees. A record was kept of each felled and each dead tree. The data taken included the diameter of stump, the average height of stump (which was usually about 1 foot), the diameter of the rot in the stump, the height to which the rot ascended in the butt of each tree, the cause of each kind of rot found, the root-rots present, the number of dead trees, the cause of death, the number of dead trees blown down, and any other facts bearing on the health of the trees. Data on 902 felled trees were obtained. Of this number, 477 were white oaks, 302 chestnuts, 61 red oaks, 45 poplars, and the remainder maples, service berries, and pines.

GENERAL CONDITION OF THE CHESTNUT.

HEALTH OF THE TREES.

All of the chestnut trees over 18 inches in diameter were found to have diseased tops; that is, some were "stag headed," while all had one or more large dead branches on them. Many of the larger chestnut trees, especially those somewhat isolated on the edges of the ridges, had been struck by lightning. These trees were not killed outright, but in many cases tops, branches, and strips of bark of varying sizes had been killed. In a few instances the bark had been partially stripped from the tree, but usually the lightning left little or no external evidence of immediate injury. A careful examination, however, showed that wide strips of bark had been killed, especially near the bases of the trees, and that little or no callus had formed around the wounds. In the majority of cases the wounds had not healed, but were gradually increasing in size. This increase was always greater at the base of the tree and could usually be traced directly to the parasitic action of the fungus *Armillaria mellea*. The typical rhizomorphs, or "shoe strings," of this fungus were present at the bases of the trees and extended 5 to 20 feet upward beneath the bark.

Of the tops, 75 per cent were infected by a pocketed or piped rot (Pl. I, fig. 1) caused by the fungus *Polyporus pilotae*, which had apparently entered through the old dead branches so common on the upper parts of chestnut trees in this region. In addition to this top-rot, 46 per cent of the felled trees were infected with butt-rot, the bulk of which was also caused by *Polyporus pilotae*.

RATE OF GROWTH.

The chestnut bark disease was not found in the region examined, but the chestnut trees, and also the oaks and poplars, were undoubtedly dying here and there from other causes. The annual rings in the chestnuts show that these trees had made a fairly rapid and vigorous growth during the first 20 or 30 years; then came a period of much slower growth, culminating in a period in which the annual



FIG. 1.—HEART-ROT IN CHESTNUT CAUSED BY *POLYPORUS PILOTAE*.

The fungus entered at the dead branch and has moved downward into the heartwood of the tree proper.



FIG. 2.—“SHOE STRINGS” OF *ARMILLARIA MELLEA* BENEATH THE BARK OF A FELLED CHESTNUT WHICH HAD BEEN KILLED BY THIS FUNGUS.



FIG. 1.—“SHOE STRINGS” OF *ARMILLARIA MELLEA* ON THE DEAD ROOTS OF A WIND-THROWN WHITE OAK.



FIG. 2.—*ARMILLARIA MELLEA* UNDER THE BARK OF TWO CHESTNUT TREES WHICH ARE JOINED AT THE GROUND.

The fungus has killed the tree in the foreground and has passed over to the other tree, where it has killed the bark for a distance of 8 feet upward and about one-third of the distance around the base of the tree.

increment was less than 1 millimeter in radius. In those trees which had been killed the annual increment in radius for the last 6 to 10 years of their life was only one-third to one-fourth of a millimeter. The average rate of increment was found to be 25 millimeters in diameter for $7\frac{1}{2}$ years of growth. This small increment indicates that the chestnut in this region is growing under very unfavorable conditions.

A clearer idea of how slowly these chestnuts have grown can be obtained by comparing the diameters of a few of these trees with those of chestnuts grown under more favorable conditions in other localities. For this purpose data are used which were published in 1905 by the Bureau of Forestry in Bulletin 53, entitled "The Chestnut in Southern Maryland," by Raphael Zon. The Forest Service has permitted the writer to use some unpublished data consisting of growth-diameter measurements made in West Virginia and Tennessee by Walter Mulford in 1905-6 and in Hyde Park, Dutchess County, N. Y., by J. G. Peters in 1905. The data from Hyde Park, where the growth conditions for chestnuts were favorable, are especially valuable for comparing with the growth data of chestnuts in New Berlin, as the two localities are in the same State. The growth data of chestnuts grown in Connecticut, included in Table I, were obtained by compiling the figures contained in Bulletin 154 of the Connecticut Agricultural Experiment Station, entitled "Chestnut in Connecticut and the Improvement of the Woodlot," by Austin F. Hawes.

TABLE I.—*Diameter measurements and average ages of chestnut trees.*

DIAMETER, BREAST HIGH (INCHES).

Age and diameter.	New York.		Connecticut.	Maryland.	Tennessee.	West Virginia.
	New Berlin.	Hyde Park.				
Age (years):						
10.....	1.6	2.5	-----	3.75	0.7	0.5
20.....	3.7	4.9	3.4	6.67	3.1	2.4
30.....	5.7	7.2	6.4	9.25	5.6	4.3
40.....	7.6	9.4	9.5	11.5	8.2	6.4
50.....	8.3	11.4	12.6	13.4	11.2	8.4
60.....	9.5	12.9	15.6	15.2	13.7	10.4
70.....	10.7	14.0	18.7	17.3	16.0	12.5
80.....	11.9	-----	21.7	18.1	18.4	14.4
90.....	12.0	-----	24.8	19.1	20.3	16.3
100.....	11.2	-----	27.8	20.0	21.7	18.2
110.....	11.3	-----	30.8	-----	22.7	19.9

AGE (YEARS).

Diameter, breast high (inches):						
6.....	32	25	29	17	32	38
8.....	46	31	35	25	39	48
9.....	56	38	39	29	44	53
10.....	65	43	42	33	46	59
11.....	80	47	45	38	49	63
12.....	90	54	48	43	53	67

From Table I it is readily seen that the chestnut at New Berlin, N. Y., has made a much slower growth than the trees from any of the other localities listed.

GENERAL CONDITION OF THE WHITE OAK.

Of the oaks in this region, the white oak (*Quercus alba*) predominates, but is intermixed with the red oak (*Q. rubra*). The tops of all the oaks appeared healthy, no "stag heads" or large dead branches being present. There was very little butt-rot of any kind in the boles. This was especially true of the area that had never been logged. In this area there occurred only 5 per cent of butt-rot and no top-rot of any kind. On the area which had been partially logged once there was a greater percentage of butt-rot due to injury to the standing timber from bruises on the roots and butts of the trees exposed to injury in logging. On this area the oak had 21 per cent of butt-rot, as against 5 per cent on the unlogged tract. Of this butt-rot, 87 per cent was caused by *Hydnum erinaceus*, which by decay makes hollows and is capable of entering through slight bruises on the trees, as well as through fire scars and other deep wounds.

ARMILLARIA MELLEA ON CHESTNUTS, OAKS, AND POPLARS.

The "shoe strings" of *Armillaria mellea* were found very abundantly on the roots and under the bark of the butts of chestnuts, oaks, and poplars. They were also occasionally found on maples and on service berries (*Amelanchier* sp.), but none were found on the white pine. These "shoe strings" were also common in the soil around the bases of the diseased and dead trees. On some of the dead chestnut trees these "shoe strings" had grown upward under the bark for 15 or 20 feet. In many instances they had made a perfect network of strings over the sapwood (Pl. I, fig. 2). There could be no reasonable doubt that this fungus was killing the chestnut and oak, since trees were found in all stages of decline when it was present. Wherever a dead piece of bark on the base of a tree was removed, the brown or black rhizomorphs of this parasite were found beneath it. In such cases a watery zone of dying bark of a dark-brown color marked the boundary line between sound and diseased tissue. Sometimes only a very small area of the bark was affected, although the roots on this side of the tree were already dead and the outer layers of the sapwood were more or less decayed. The rotten sapwood is watery, white in color, soft, and easily broken. On a chestnut tree 18 inches in diameter this fungus had killed an area 14 inches wide at the ground and extending 15 feet upward, while the "shoe strings" had grown up under the bark a distance of 8 feet. The top of this tree was dead. In three instances where chestnut trees had been struck

by lightning this disease was found following up and enlarging the wounds. Many of the white oaks killed by this fungus had been blown down. In every case the upturned roots were covered with a network of the black rhizomorphs (Pl. II, fig. 1). Several groups of two to four chestnut trees which had originated from sprouts around a common stump were found killed by this root-rot. Plate II, figure 2, shows two trees from a common base, one being already dead and the other badly diseased. In the latter the bark and roots on the side adjacent to the dead tree were killed for about one-third of the distance around the base, and the rot had extended up the tree 8 feet under the bark.

PERCENTAGE AND SIZE OF CHESTNUTS KILLED BY *ARMILLARIA MELLEA*.

Of the 302 felled chestnut trees examined, 64, or 21 per cent, had been killed by the *Armillaria* root-rot. The average diameter of these killed trees was 12 inches; the largest chestnut killed was 26 inches and the smallest 3 inches in diameter. Trees of all diameters between these limits were found diseased and killed. Of these trees, 10 had a diameter of 3 to 5 inches, 13 of 6 to 10 inches, 22 of 11 to 15 inches, and 19 of 16 to 26 inches. From this it follows that a greater percentage of the large chestnut trees was killed by this root-rot than of the smaller and younger trees. Of the 64 chestnut trees killed, 41, or 64 per cent, were over 10 inches in diameter. The average diameter of these 41 trees was 16 inches. In the white oak, just the reverse occurred; a greater percentage of the smaller and younger trees was killed than of the larger and older ones.

PERCENTAGE AND SIZE OF OAKS KILLED BY *ARMILLARIA MELLEA*.

Of the 477 oaks checked, 130, or 27 per cent, had been killed by the *Armillaria* root-rot. The average diameter of these killed trees was 7 inches, as compared with 12 inches in the chestnut. The largest oak killed was 18 inches and the smallest 2 inches in diameter. Trees of all sizes between these two extremes were affected. Of these white oaks, 39 ranged in diameter from 2 to 5 inches, 70 from 6 to 10 inches, and 20 from 11 to 15 inches, with only 1 over 15 inches. Of these 130 white oaks which had been killed, 84 per cent were less than 11 inches in diameter and only 16 per cent were over 10 inches in diameter, as compared with 64 per cent in the case of the dead chestnut trees in the same locality.

Of the white oaks killed by this root-rot, 46 had been overthrown by the wind, while only 2 of the dead chestnuts had been blown down. Of the wind-thrown oaks, 26 were from 6 to 8 inches in diameter, showing that the smaller as well as the larger sizes of white oaks were not as easily uprooted as those of medium diameter.

NUMBER AND SIZE OF POPLAR TREES KILLED BY *ARMILLARIA MELLEAE*.

In addition to the dead chestnuts and oaks, the writer counted 29 poplar trees which had been killed by this root-rot out of a total of 45 examined. Many of these were small and much suppressed, although there were 12 that ranged from 6 to 9 inches in diameter. These larger poplars were not suppressed and under normal conditions ought not to have died.

GENERAL DISCUSSION OF THE DISEASED CHESTNUTS AND OAKS.

Why a larger percentage of small white oaks should be killed than of small chestnut trees is difficult to explain from the data at hand. However, it seems to be evident, judging from the location of the smaller white oaks which were killed, that the majority of the trees under 11 inches in diameter were much suppressed and for this reason would perhaps succumb more quickly to disease than trees growing under more favorable conditions. Nothing was found to indicate that the larger white oaks which had been killed were in poor health before they were attacked by this disease. It would seem that the disease, having gained a foothold in the soil, simply spread to the large white oaks and finally killed them. As far as could be determined, the fungus *Armillaria mellea* was the primary cause of their death. No white oaks in this region were seen which had been struck by lightning; this was in marked contrast to the number of chestnut trees in the same territory which had been struck.

The only explanation which can be offered for the small percentage of young chestnut trees which had been killed by the root-rot is that the present stand of chestnuts originated mainly from sprouts, and the young trees therefore had the large root system of the parent stump from which to draw nourishment. As a result, their growth would be very vigorous during the first 10 or 15 years of life. Under such conditions one would not expect a hemiparasite like *Armillaria mellea* to attack them as readily as it did the suppressed young oaks. This, however, does not explain why the disease has killed so many of the older and larger chestnut trees, unless the old stumps acted as a breeding ground for the mycelium until it obtained a foothold in the living trees. The chestnuts undoubtedly were growing under unfavorable conditions, a fact proved by the very small annual increment. This would make them more subject to diseases of this type. The weather conditions in the past may have been such as to weaken the trees and thus make them more susceptible to this rot. For instance, in the year 1913 the chestnut trees had lost two sets of leaves from late frosts, and at the time this investigation was made (June 19, 1913) the third set of leaves was not fully developed, and many of the trees were so badly injured that they apparently were not going to leaf out at all.

AREAS INFECTED BY *ARMILLARIA MELLEA*.

Ten distinct badly diseased areas of varying sizes were found in which the *Armillaria* root-rot had killed many trees. On one area 40 yards in diameter, both chestnuts and oaks of large size had been killed, including 6 chestnuts with diameters of 8, 8, 10, 12, 14, and 16 inches, and 4 oaks with diameters of 8, 13, 14, and 14 inches, respectively. Another rather large area had 34 dead trees scattered over it; of these there were 25 white oaks, 6 chestnuts, and 3 poplars. These trees ranged from 3 inches to 26 inches in diameter. On none of these diseased areas were all of the trees killed; some were alive and apparently in good health. This root-rot apparently was much worse where the soil was very damp, or even wet, during certain portions of the year.

Mr. H. M. Sears, of the Forest Service, in a report entitled "Deterioration of Blight-Killed Chestnut in Northern New Jersey," mentions the presence of the rhizomorphs of *Armillaria mellea* beneath the bark of some of the dead chestnut trees. No evidence was advanced, however, to show that this fungus had attacked the chestnut trees before they died.

ARMILLARIA MELLEA ON CHESTNUTS IN NORTH CAROLINA.

AREA EXAMINED.

On a recent trip through North Carolina, the writer found a rhizomorphic root-rot prevalent on the chestnut near Mount Airy, N. C., which is apparently the same as that found in New York. As the investigations in North Carolina were devoted primarily to the heart-rots of trees, very little time was given to this root-rot problem. However, some data on the character and extent of the disease were taken. The area studied was located about 6 miles east of Mount Airy, near Brim, N. C.

CHARACTER AND GENERAL CONDITION OF THE TIMBER.

The timber was located on the ridges and slopes and consisted of a mixed stand of chestnut and oak growing in a rather thin, more or less rocky soil with a red-clay subsoil. Chestnut oak (*Quercus prinus*) was the principal species of oak, but white oak (*Q. alba*), black oak (*Q. velutina*), and red oak (*Q. rubra*) were also present. All of the chestnut over the area examined was deteriorating, 90 per cent was stag headed and much was actually dying, while from 20 to 30 per cent was already dead. There was little or no sprout reproduction from the bases of the affected trees. Because of the rotted condition of the roots, the dead and dying trees in this region are easily blown down. According to resident millmen, this dying of the chestnut has become very pronounced during the last fifteen to twenty years.

The chestnut over this area originated mainly from seedlings, and, judging from the large annual increment, it made a healthy and vigorous growth before this trouble appeared.

NUMBER AND CONDITION OF THE INDIVIDUAL TREES EXAMINED.

The roots of 71 dead or badly diseased trees were examined. Of this number, 64 were chestnuts, 5 black oaks, 1 a chestnut oak, and 1 a sassafras. Of the chestnuts, 55 were already dead and 23 of them had been blown down when the studies were made. This afforded an opportunity to examine the condition of the roots. Nine of the living chestnuts studied were either dying or badly stag headed. Chestnut trees of all sizes were found dead or dying. Of the 64 chestnuts studied, 7 ranged in diameter from 4 to 10 inches, 23 from 11 to 20 inches, 29 from 21 to 30 inches, and 5 had diameters greater than 30 inches. An occasional black oak was found dead or badly stag headed, especially when adjacent to the worst affected chestnuts. The chestnut oaks, however, seemed to be vigorous and in the best of health. Especially valuable data were obtained from a wind-thrown chestnut 38 inches in diameter, which had been living but was badly stag headed when blown down. This tree was blown down only 11 days before the data were taken. The condition of its roots and stool was, therefore, exactly the same as when alive. When this tree was overthrown, several of the most superficial roots were still alive, but all of the deeper roots were dead. The sapwood of the dead roots was white rotted and covered with a network of black rhizomorphic strands. This rot was gradually encroaching on the living roots and killing them. The tree stood on the top of a rocky red-clay ridge, with the bulk of its roots within 2 feet of the surface of the soil.

All of the 71 trees examined had the "shoe strings" of *Armillaria mellea* on their roots. They were also found in a few instances extending from 3 to 8 feet upward beneath the bark on both living and dead trees. As a rule, however, the rhizomorphs were inconspicuous and were confined mainly to the roots and stools of the affected trees. The area studied was very limited, and no attempt was made to examine the roots of a large number of living trees. The data given here are therefore too meager to justify any positive opinion as to the amount of damage done by this root-rot in North Carolina. However, the prevalence and apparent destructiveness of this fungus over the area examined seem to point to it as very probably an important factor in the gradual recession of the chestnut in that State. If such an organism is at work, it would in a large measure explain the hitherto unexplained phenomena associated with this recession, such as the lack of reproduction from sprouts and the failure of the chestnut to reoccupy its former territory. A more extended investi-

gation covering the entire range of this recession may or may not show the presence of this root-rot as abundantly over the other regions involved as it is at Brim. The identification of this root-rotting organism as it occurred both in New York and in North Carolina was made from the rhizomorphic strands present on the affected trees. No sporophores were found, as the time of the year during which the diseased trees were examined was not the proper season for their appearance.

CONCLUSIONS.

(1) The chestnut near New Berlin, N. Y., and at Brim, N. C., is deteriorating. This is clearly shown by the small annual increment during recent years, by the thin sapwood, by the large percentage of diseased and stag-headed tops, and by the number of dead and dying trees. This decline is probably due to several factors, one of which is the root-rotting fungus *Armillaria mellea*, but it should be noted that in spite of these facts the chestnut bark disease (*Endothia parasitica*) is not present in these localities.

(2) *Armillaria mellea* can become an active parasite under favorable conditions, especially in chestnuts and oaks, killing not only suppressed trees in the forest, but also those that are growing under more favorable environments.

(3) The prevalence and apparent destructiveness of this fungus over the area examined in North Carolina seem to point to it as very probably an important factor in the gradual recession of the chestnut in that State.





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Contribution from the Bureau of Entomology, L. O. Howard, Chief.

May 19, 1914.

THE ROSE APHIS.¹

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INTRODUCTION.

Because of its beauty, and its hardiness as an outdoor plant, the rose has long been one of the most popular ornamental flowers in this country. Yet in spite of the appreciation given it the blossoms and young foliage are frequently permitted to suffer great damage from the rose aphid (*Macrosiphum rosæ* L.), whereas a few minutes' attention on the part of the owner each week would remedy the injury and greatly increase the beauty of the bloom and foliage. This common rose pest was first described by Linnæus² in 1735, and since that time has often been mentioned in systematic works by both European and American writers. However, the writer has seen no account of it in American entomological publications in which the life history, habits, or control have been treated with anything approaching completeness. The writer, therefore, in 1910, while stationed at Los Angeles and under the direction of Dr. F. H. Chittenden, began a study of the life history and habits of the rose aphid in its occurrence on the outdoor roses so largely grown in southern California. At a later period the work was carried on to some extent in Washington, D. C. While this study is still incomplete, enough has been learned to give the rose lover a fair understanding of the habits of this insect and of the means for controlling it.

RECENT RECORDS.

During the fall and winter of 1909 and the spring of 1910 the writer found the rose aphid attacking roses and causing extensive damage to the buds and blossoms throughout the city and in the vicinity of Los Angeles. On October 21, 1909, when first observed,

¹ This bulletin is of interest to rose growers everywhere.

² Linnæus, C., *Systema Natur.*, ed. 12, vol. 1, pt. 2, p. 734, 1767.

this insect had become quite common, and many of the buds were covered with the females and young. Examination of surrounding localities disclosed the same conditions of infestation. The aphides increased rapidly until the cold weather in December checked, although it did not entirely stop, their reproduction and growth. In January, warmer weather again prevailing, the rosebushes began to grow rapidly, and the rose aphid became very abundant on the tender stems and buds. It continued abundant and developed rapidly during the months of February and March, although syrphus-fly larvæ devoured thousands. Early in April, however, there occurred several very warm days when the temperature rose to 100° or 101° F., and immediately the numbers of aphides were greatly reduced. Afterwards the aphid occurred scatteringly on the roses and caused very little damage. This was due in part to extreme heat and the work of parasitic and predaceous enemies, and to the fact that in June the roses became more or less dormant and ceased active growth for some weeks. By the middle of August the rosebushes had resumed active growth, and this insect again began to increase rapidly and to cause damage, continuing to multiply and injure the roses until October 1, 1910, when observations ceased.

At Washington, D. C., during October and November, 1912, this aphid was very abundant and injurious to roses grown in the yards and gardens of the city. But by November 29 only a few aphides remained on the plants, although these persisted as late as December 16.

DESCRIPTION.¹

The rose aphid occurs in two forms, one in which the body is of a pinkish color and the other in which the pink is replaced by bright green. Both forms may be present on the same bush or twig, and in some cases all on one bush may be green and all on another near it pink. It would appear from the writer's observations that the green aphides are much more abundant during the cooler months than the pink forms.

The winged female (fig. 1, *a*) has a pear-shaped body which in one form is pinkish and in the other bright green. The thorax is largely black, apparently deeper black in the green form, and there is a row of black spots on either side of the abdomen. These colors may vary slightly in shade. The antennæ, cornicles, ends of femora, and the tarsi are black, while the other parts of the legs are whitish. In both pink and green forms, however, the head may be entirely black, and the black antennæ and cornicles may be hyaline at the tips. The

¹ Another aphid commonly found on the rose is known as the small green rose aphid (*Myzus rosarum* Walk.), but this can be distinguished by its smaller size and by the fact that it has only a green form. This species is shown in figure 2, in both winged state (*a*) and wingless state (*b*) with many details of structure. This aphid will yield to the same treatments as the common rose aphid.

eyes are dark red, the cauda is yellowish, and the veins of the wings are light yellow. The legs, antennæ, and cornicles are very long and slender, the antennæ longer than the body. The length of the body is about one-twelfth of an inch (2.5 mm.) from the front to the tip of the cauda and the length of wing about one-sixth of an inch (4.2 mm.).

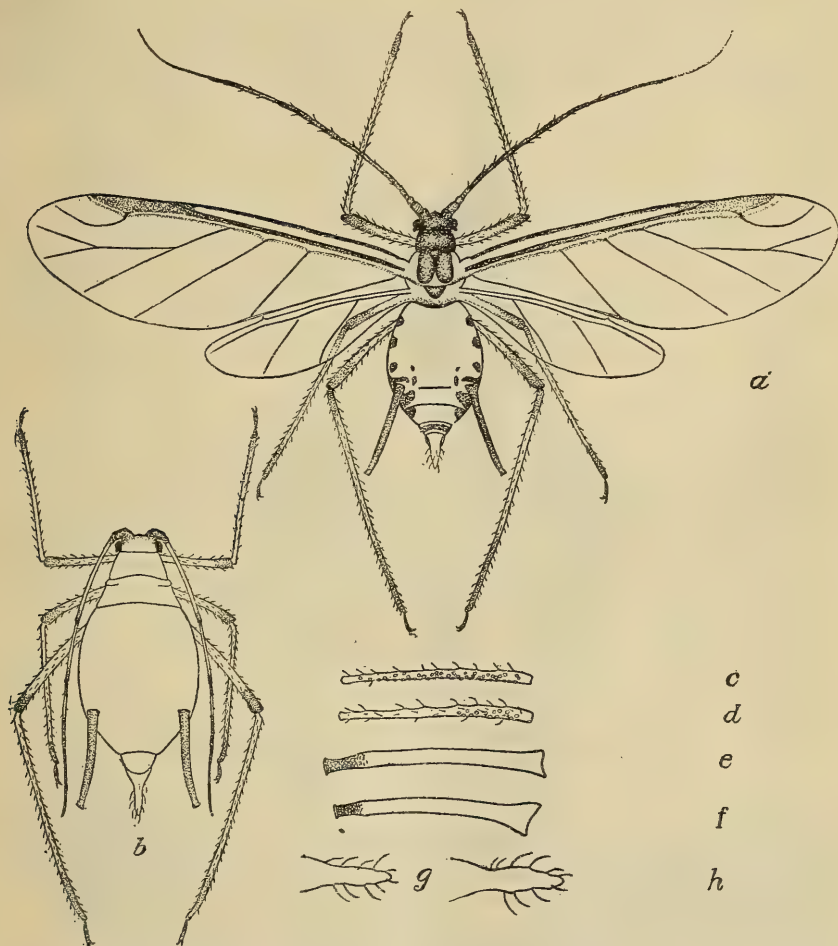


FIG. 1.—The rose aphid (*Macrosiphum rosæ*): a, Winged viviparous female; b, wingless viviparous female; c, e, g, third antennal article, cornicle, and style, respectively, of winged female; d, f, h, same of wingless female. Greatly enlarged. (After Essig.)

In the wingless female, also (fig. 1, b), the body is pear shaped, more or less blunted at the posterior end, and pinkish or bright green in color. The eyes are red. The antennæ are as long as the body and very light green. The cornicles and legs are long and slender and light green. The length of the body is about one-twelfth of an inch (2.5 mm.).

DISTRIBUTION.

The rose aphid is distributed over the entire United States, having been recorded from Massachusetts, New Jersey, Illinois, Iowa, Minnesota, Colorado, and California. It also occurs in Europe, from which country it was first described.

The writer has collected it in southern California on all the commoner varieties of roses growing outdoors and has also taken it, in 1913, in Connecticut, Maryland, the District of Columbia, and Virginia.

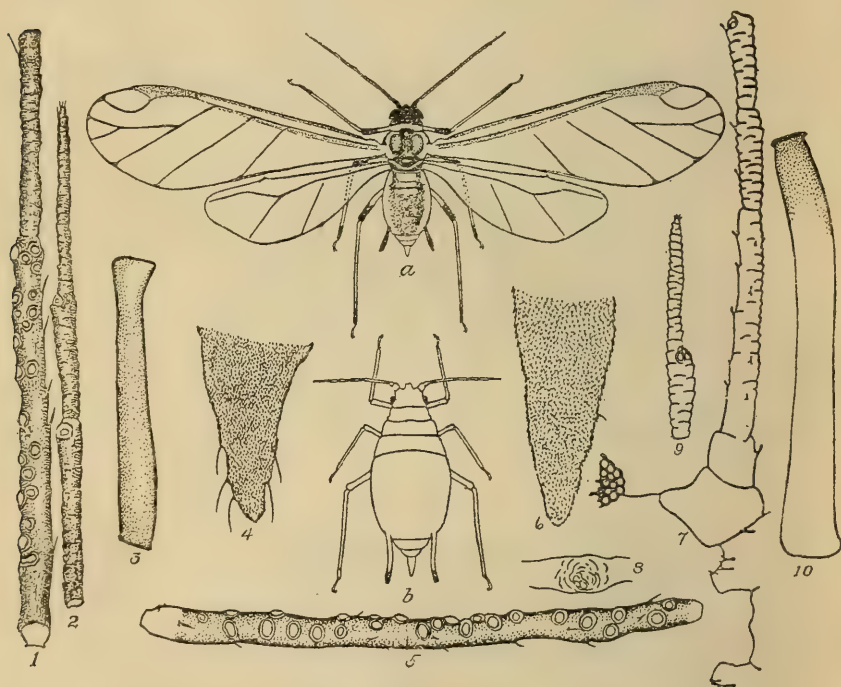


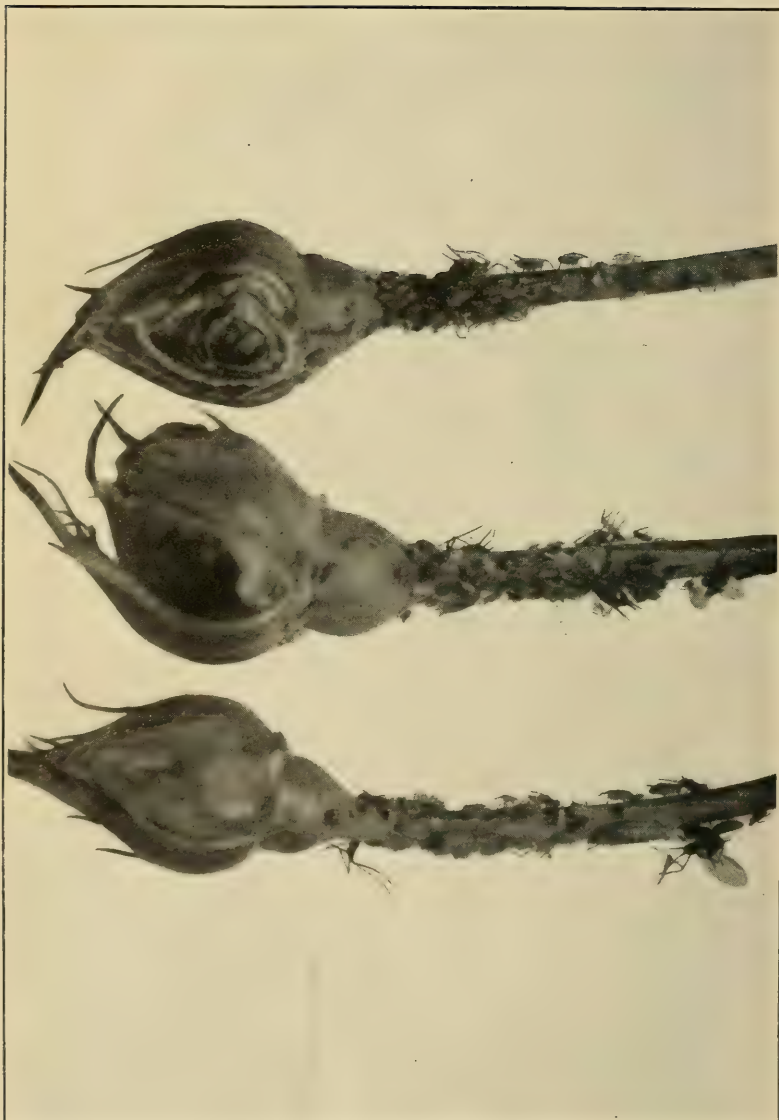
FIG. 2.—The small green rose aphid (*Myzus rosarum*): a, Winged viviparous female; b, wingless viviparous female; 1, 2, antennal articles of winged female; 3, cornicle of same; 4, style of same; 5, third antennal article of same; 6, style of wingless female; 7, 8, front and antenna of same; 9, cornicle of same; 10, process of sixth antennal article of same. Greatly enlarged. (After Essig.)

CHARACTER OF INJURY.

This insect, like all aphides or plant-lice, obtains its food by suction. The slender beak with which it is furnished is inserted into the plant attacked, and through this the plant juices are taken up. The rose aphid in feeding chooses the tender and growing shoots and flower buds or the young unfolding leaves, and by feeding in large numbers checks the growth, the leaves and flowers being curled or distorted and prevented from attaining their perfect form. (Pls. I, II.)



ROSE BUDS SHOWING INJURY BY THE ROSE APHIS (*MACROSIPHUM ROSAE*). ENLARGED.
(ORIGINAL.)



ROSE BUDS SHOWING COLONIES OF THE ROSE APHIS (*MACROSIPHUM ROSAE*). ENLARGED. (ORIGINAL.)

Because of the feeding of this rapidly reproducing insect, the flowers may be largely spoiled for decoration, or, since the rose aphid, like all aphides, secretes a sweet sticky liquid called honeydew, the appearance of the foliage may be ruined because of the sooty mold that develops where this honeydew has collected.

HABITS.

About the time the wingless females become ready to reproduce they leave the parent colony and crawl or migrate to various parts of the rosebush. Upon finding a growing twig or bud, the female settles down with the head pointed toward the ground and begins to feed. In a day or two she begins to give birth to young, which ordinarily range themselves close together around the tender bud or stem behind the adult, and with the heads all pointing downward begin feeding. (Pl. II.) As the stem or bud becomes crowded many move out until the flower itself is covered with them. As the aphides continue feeding a large amount of honeydew is produced which falls to the leaves beneath, causing a disagreeable stickiness on the leaf, which either becomes covered with dust or black from sooty mold.

A very slight jar causes the aphides to let go with one pair of legs, and all begin to twitch from side to side on the remaining four legs until quiet is restored, while a severe jar causes many to fall to the ground. A number of the young develop wings, and when mature they fly to other buds and form new colonies.

When the nymph changes to the winged form the skin splits along the dorsum and the adult crawls slowly out. When newly transformed the adult is light reddish or green in color, with antennæ, beak, legs, and cornicles whitish or hyaline, and the wings, which are also white in color, appear as little sacks on the back. In about 20 minutes the wings become fully expanded, and two days later the aphid has the colors of the mature insect.

LIFE HISTORY AND REPRODUCTION IN CALIFORNIA.

In a climate as mild as that of southern California this insect reproduces continuously throughout the year and undoubtedly is capable of reproducing asexually and viviparously for an extended period. While under observation it has been found giving birth to living young throughout the entire year, and the writer has been unable to find eggs during the same period. It may be that in a climate such as exists in that part of the country, where very cold weather does not occur and where the roses continue to grow all

winter, sexual forms and eggs of this species are not produced, at least until parthenogenetic reproduction causes deterioration.¹

In other parts of this country where the winter conditions are more severe the rose aphid passes the winter in the egg stage. At Washington, D. C., on November 29, 1912, the writer found a few eggs of this species laid on the twigs of rosebushes. These small, oval, shining black eggs were fastened to the sides of dormant buds.

Buckton² described the eggs as follows:

The eggs are at first yellow, but subsequently they become black by reason of certain changes shown by Balbiani to result from fecundation. Previous to this time the outer coats are sufficiently thin and transparent to allow the process of segmentation to be observed.

Notwithstanding the great size of the ovum the female may carry five or more. These, however, are not equally large, but are found to vary in bulk as they approximate maturity and the time for expulsion.

In California during the fall and spring, while the rose shoots are growing vigorously and producing much tender growth, the rose aphid reproduces very rapidly. During the summer, however, the rate of reproduction seems to be much reduced, and, owing to the attack of natural enemies, this insect does not greatly increase. In the winter the time of development is lengthened and the rate of reproduction is considerably less.

During the months from October, 1909, to March 10, 1910, the author endeavored to ascertain the number of young produced and the average rate of reproduction under normal conditions. This was done by marking rose twigs having a single female and, after examining them every other day, removing all the young born at that time. Thus the aphides were exposed to temperature, rain, and all other natural conditions which might influence them. Under this method many females were knocked from the bushes and lost, but as this would occur naturally it demonstrates fairly well the average rate of reproduction, if not the maximum, under the conditions most favorable for the adult. These records have all been included in Table I.

¹ B. M. Lelong, in the Report of the State Board of Horticulture for California, for 1889, page 213, states that "Kyber, in 1815, has had the rose aphid producing young for four years. From his carefully conducted experiments and from corresponding ones made by other naturalists a law has been deduced, which we dare not destroy, 'that under certain circumstances, a female aphid may without coupling continue propagating to infinity, provided that the necessary conditions for the development of the young—food and heat—are not wanting.'"

² Buckton, G. B., Monograph of the British Aphides, vol. 1, p. 107-108, 1875.

TABLE I.—*Reproduction and development of the rose aphid, Macrosiphum rosae, in southern California, 1909-10.*

Date of birth of female unknown; gave birth to first young Oct. 20, 1909:		Date of birth of female unknown; gave birth to first young Nov. 19, 1909:	
	Number of young.		Number of young.
Oct. 20.....	4	Nov. 19.....	2
21.....	5	20.....	2
22.....	5	21-22.....	4
23.....	7	23.....	4
24.....	5	24.....	2
25.....	7	25.....	2
26.....	(¹)	26.....	(²⁵)
Total.....	33	27.....	2
Average per day.....	5½	28.....	2
		29.....	2
Date of birth of female unknown; date of birth of first young un- known:		30.....	(¹)
Nov. 3.....	6	Total.....	22
4.....	4	Average per day.....	2
5.....	2		
7.....	4	Date of birth of wingless female, green form, unknown; gave birth to first young Nov. 19, 1909:	
8.....	(¹)	Nov. 19.....	2
Total.....	16	20.....	5
Average per day.....	3+	21-22.....	6
		23.....	5
Female born Nov. 18, 1909; gave birth to first young Dec. 6, 1909: ²		24.....	4
Dec. 6.....	1	25.....	3
8.....	5	26.....	(²⁵)
10-11.....	6	27.....	4
12.....	3	28.....	(¹)
13-14.....	4	Total.....	29
15-16.....	9	Average per day.....	3+
17.....	2		
18-19.....	3	Wingless female born Nov. 18, 1909; gave birth to first young Dec. 6, 1909: ²	
20-21.....	6	Dec. 7-8.....	3
22-23.....	5	8.....	(⁵)
25.....	2	10-11.....	3
28.....	(³)	13.....	7
Total.....	46	15-16.....	7
Average per day.....	2½	17.....	3
		18-19.....	6
Date of birth of winged female, red form, unknown; date of birth of first young unknown:		20.....	1
Nov. 18.....	⁴ 18	21.....	(³)
19.....	3	Total.....	30
20.....	5	Average per day.....	2
21-22.....	12		
23.....	10		
24.....	(¹)		
Total.....	48		
Average per day, about	6		

¹ Aphid lost.² Period from birth to reproduction, 18 days.³ Aphid dead.⁴ Up to date.⁵ Rain.

TABLE I.—*Reproduction and development of the rose aphid, Macrosiphum rosae, in southern California, 1909-10—Continued.*

Date of birth of female unknown; gave birth to first young Jan. 3, 1910:		Winged female, red form; gave birth to first young Mar. 3, 1910—Con- tinued.	
	Number of young.		Number of young.
Jan. 3.....	2	7.....	5
4.....	2	8.....	3
6.....	9	9.....	(¹)
8.....	(¹)		
Total.....	13	Total.....	32
Average per day.....	3	Average per day.....	5 $\frac{1}{3}$
Winged female, red form; gave birth to first young Mar. 3, 1910:		Mar. 7.....	5
Mar. 3.....	5	8.....	5
4.....	5	9.....	7
5.....	9	10.....	(¹)
6.....	5	Total.....	17
		Average per day.....	5 $\frac{2}{3}$

Two females were observed that produced 30 and 40 young, respectively, after which they died under normal conditions. They produced young on an average of 2 and 2 $\frac{1}{2}$ per day for 15 and 20 days, respectively, during the month of December. Other females observed during the same period, but lost possibly before reproduction was completed, gave birth to from 15 to 45 young at an average of 3 $\frac{1}{2}$ per day. Two females observed in the month of March, however, produced young at the rate of 5 $\frac{1}{3}$ and 5 $\frac{2}{3}$ a day, showing quite plainly how the reproduction was accelerated during the prevalence of warmer temperatures. Two females in October reproduced young at the rate of 5 $\frac{1}{2}$ a day for 6 days, or until lost.

From these observations it may be said that this insect is able to reproduce for at least 20 days during the winter in southern California and to give birth to as many as 45 young, while in the warmer seasons the number of young is probably greater and the period of reproduction is considerably shorter. The reproduction experiments were too few in number to justify making any statements more generalized than these.

LIFE HISTORY AND REPRODUCTION IN THE GREENHOUSE.

During the fall of 1912 the rose aphid was under the direct observation of the writer in the insectary greenhouse at Washington, D. C., and the life cycle was observed for a few individuals.

A wingless female born October 10 matured and gave birth to young on October 19, or in 9 days. During the next 7 days she gave birth to 45 young, or an average of 6 $\frac{2}{3}$ per day.

¹ Aphid lost.

Of four other aphides, born on October 10, two became adult and gave birth to young on October 22, or in 11 days, while another required 12 days, and the fourth 13 days.

Another aphid was born on October 19 and emerged as a winged female on November 3, reaching maturity in 15 days. This insect lived as an adult for 17 days and gave birth to living young for 14 days. During this time she gave birth to 87 young, or an average of $6\frac{3}{4}$ per day. During this time the average mean temperature was 67° F.

LIFE CYCLE IN CALIFORNIA.

During the winter months of 1909-10 the life cycle was observed in California in a number of cases. Aphides born on the 18th of November became adult wingless females and began to reproduce young in from 15 to 18 days, and in two cases the offspring of these same insects became mature and began to reproduce in from 18 days for wingless females to 21 days for winged females. Aphides born November 26 emerged from nymphal skins as winged adults in from 23 to 25 days. Thus the wingless forms developed in all cases from 7 to 8 days sooner than winged forms.

This was the maximum life cycle, and during the rest of the year the growth must have been much faster, but observations were not made owing to press of other matters.

GENERATIONS.

Taking 25 days as a maximum, this would allow more than 12 generations annually, but with the shorter life cycle required during the warmer part of the year this number must be exceeded by at least 7 or 8 generations. In greenhouses there are probably 25 to 30 generations in a year.

LONGEVITY.

During the winter these insects are long lived for such delicate creatures. One lived under the direct observation of the writer for 40 days and another for 33 days. Probably this is longer than for the same insect the rest of the year.

NATURAL CONTROL.

RAINS.

In southern California the rainy season extends from about October 1 to May or June. Usually before the rains set in the weather becomes cooler, but the rains are not as a rule hard and dashing, as are those so fatal to aphides in the East, and this apparently explains their slight effects as observed on the rose aphid. Undoubtedly some are washed away and destroyed by rain, but not to the extent occurring in the East, although reproduction seems to be greatly checked during a rainstorm. In the East this insect is many times nearly exterminated by a hard, dashing rain.

HEAT.

During the early part of April, 1910, when the aphid was very abundant on the roses throughout the entire city of Los Angeles, three or four very hot days occurred during which the temperature rose as high as 100° F., and within a day or two thereafter the numbers of this aphid had become very much diminished. After this it did not seem to occur in large numbers again until about the middle of August.

BIRDS.

On March 19, 1910, the writer, with field glasses, watched a white-crowned sparrow (*Zonotrichia leucophrys leucophrys*) on a rosebush, 10 feet away, eating the rose aphides as fast as it could pick them from the bush. This was continued for fully 10 minutes, during which time many hundreds must have been eaten, as the plant was almost cleaned up by this bird.

On March 30, 1910, a California house finch (*Carpodacus mexicanus frontalis*) was observed by the writer eating this aphid from a rosebush for fully 15 minutes.

PARASITIC INSECT ENEMIES.

There are many different species of parasitic insect enemies that attack aphides, and some of these will attack the rose aphid. On June 13, 1910, many specimens of *Macrosiphum rosæ* were found which showed signs of parasitism by an undetermined insect. These aphides were rounded and fastened to the underside of the rose leaves. The parasite when full grown had killed the host and, cutting its way out beneath the body, spun a tiny cocoon between it and the leaf. Unfortunately all of the parasites failed to emerge. While the parasite was not rare, at least during the past year, it did not seem to check the rose aphid to any extent.

Ephedrus incompletus Prov., a braconid, was reared by the writer from this aphid at Washington, D. C., in 1912.

PREDACEOUS INSECTS.

Among the predaceous enemies the larvæ of syrphus flies and ladybirds were observed feeding on the rose aphid, and without a doubt the most important check to this insect in 1910 was due to the larvæ of syrphus flies. While these did not seem able to clear a plant altogether, still it was many times observed that strong thriving colonies of 50 to 60 aphides or more would be reduced by these insects in one or two days to a mere scattering here and there. During the year 1910 five different species of Syrphidæ were reared from larvæ feeding on *Macrosiphum rosæ*. These were *Syrphus ribesii* L. (fig. 3), *Syrphus opinator* O. S., *Allograpta fracta* O. S., *Eupeodes volucris* O. S. (fig. 4), and *Lasiophthicus pyrausti* L.

The adults of all these species seemed to have similar habits. They flew swiftly from twig to twig and hovered over them in the bright sunlight, the wings moving with extreme rapidity, always with a distinct humming sound. From time to time they alighted on the twigs or leaves and searched here and there for colonies of the aphid. The abdomen was generally kept in throbbing motion, and when an egg was to be laid a long slender ovipositor was thrust out and the egg was placed on a leaf or twig in the midst of or near the colony of the host insect. It was noticed that certain bushes shaded from the sun after 1.30 p. m. were immediately deserted by these flies until the next day.

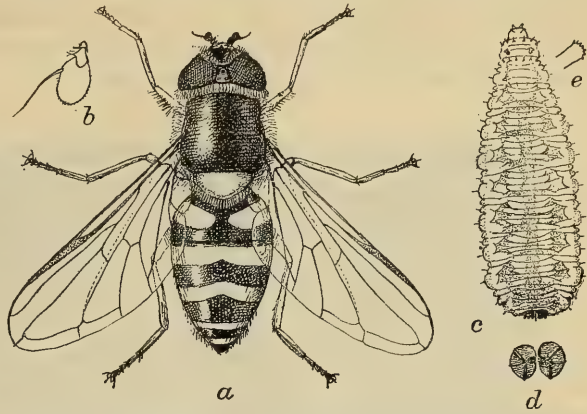


FIG. 3.—*Syrphus ribesii*, an enemy of the rose aphid: *a*, Fly; *b*, lateral view of head; *c*, larva or active immature form; *d*, anal spiracles; *e*, thoracic spiracle of same. All much enlarged. (From Chittenden.)

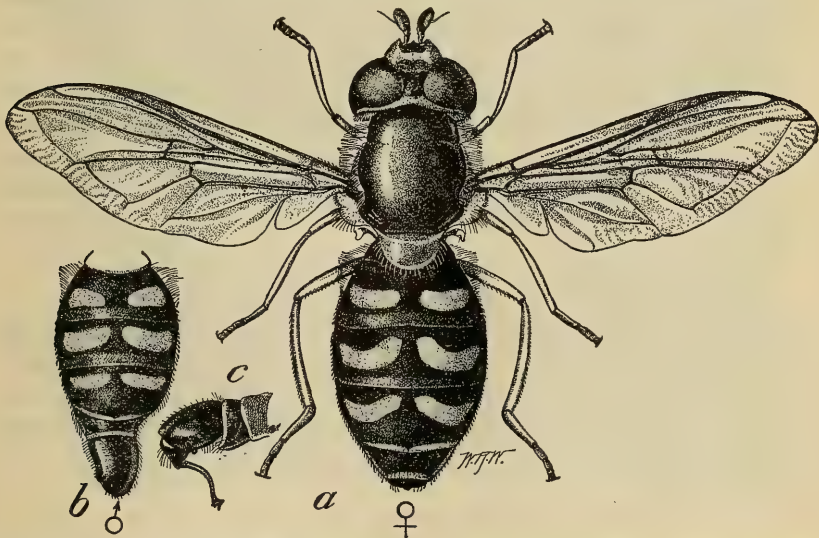


FIG. 4.—*Euxepodes volucris*, an enemy of the rose aphid: *a*, Female fly; *b*, abdomen of male fly; *c*, hypopygium of male fly. Much enlarged. (From Webster and Phillips.)

The rearing of five different species of syrphus flies from larvæ found feeding on the rose aphid rather surprised the writer, and he regrets that lack of time has prevented a continuation of the work

that it might be ascertained if other species would also be commonly reared.

Although the ladybird *Hippodamia ambigua* Lec. was observed during the entire time occupied by the observations on the rose aphid, it occurred in small numbers, and on only one or two occasions did it seem to be feeding on *Macrosiphum rosæ*.

DISEASE.

On March 14, 1910, after a night of rain, one winged and two wingless aphides were found enlarged to fully five times their regular size, as if bloated. This was probably due to a fungous disease.

EXPERIMENTS WITH REMEDIES.

The abundance of the rose aphid is so marked in many years that frequently almost daily complaints of damage are made in the District of Columbia and vicinity. Wherever it has been convenient or desirable to eradicate this species on small acreages of plants, water, applied with a garden hose or syringe, has been the remedy employed, not alone by the writer but by many persons resident in Washington. Indeed this treatment, which consists in directing a forcible stream of water against the affected portions of the plants has been one of the standard remedies advised. Experiments have been made by Dr. F. H. Chittenden, by Mr. C. H. Popenoe, and by Mr. A. B. Duckett, all in the District of Columbia and vicinity. In other regions, Mr. W. B. Parker has undertaken experiments with nicotine sulphate, and the writer has conducted quite a series of experiments with the same compound. Among other compounds used by Messrs. Chittenden and Popenoe for this species are aphid punk and other nicotine papers, always with gratifying success. While treating other forms of insects on roses, such as "slugs" and thrips, the aphides were always the first to perish.

EXPERIMENTS IN THE DISTRICT OF COLUMBIA AND VICINITY.¹

On March 28, 1913, at Washington, D. C., four rosebushes in the greenhouse, well infested by the rose aphid, were sprayed with "black-leaf 40," a preparation guaranteed to contain 40 per cent of nicotine sulphate, in combination with whale-oil soap in the following formula:

Nicotine sulphate	ounce..	$\frac{1}{2}$
Whale-oil soap	pound..	$\frac{1}{2}$
Water	gallons..	2 $\frac{1}{2}$

Although the solution slightly injured the terminal buds and the tender shoots, the results were all that could be expected, 100 per cent of the aphides being killed. It is believed that the solution could have been reduced 25 per cent in strength with equally good results.

¹ By A. B. Duckett.



SPRAYING ROSE BUSH WITH COMPRESSED-AIR SPRAYER BY HAND.

On April 23, at a Virginia station near Washington, a number of large rosebushes trained on the side of a house and well infested with aphides were sprayed. Both winged and wingless forms of aphides were present. Nicotine sulphate was applied, with and without the use of soap as in the previous formula, at the rate of 1 part to 1,000 of water. In the experiments without the use of soap some difficulty was found in obtaining a spreading action of the spray, and consequently only about 90 per cent of the aphides were reached. It is believed that all reached by the spray were killed. When nicotine sulphate was used at the rate of 1 part to 1,400 parts of water and 1 part to 1,500 parts of water, results were not satisfactory, only about 25 and 10 per cent, respectively, being destroyed. With the use of soap 100 per cent of the aphides on the vines were killed, the results being very satisfactory. At the rate of 1 part of nicotine sulphate to 1,400 of water with a laundry soap added, 90 per cent of the aphides were killed; whereas the results with nicotine sulphate at 1 part to 1,600 of water and 1 part to 1,800 of water in combination with soap were unsatisfactory, only 70 per cent and 50 per cent being killed.

In these experiments a compressed-air sprayer with Bordeaux type of nozzle was used at an estimated pressure of 90 pounds, and a fine but driving spray was employed. The water used for the dilution of the insecticide was particularly soft, but contained a very small proportion of sulphur.

From these experiments it may be concluded that nicotine sulphate at the higher dilutions as used in these experiments is much more effective against the rose aphid when used in combination with whale-oil or other soaps, since the spreading action thus induced is much more favorable. The plants may, however, be injured in case the spray solution is too strong. It is not believed that the injury shown in the experiments was caused by nicotine sulphate used at too great a strength, since it has been applied experimentally to roses in the greenhouse at the rate of 1 part nicotine sulphate to 15 parts of water without injury other than the appearance of mildew, undoubtedly superinduced by the spraying. It is apparent from the results obtained that a spray can not be employed weaker than 1 part of 40 per cent nicotine sulphate to 1,400 parts of water with satisfactory results unless in combination with whale-oil or other soap.

ARTIFICIAL CONTROL IN THE GARDEN.

Experiments have been conducted against the rose aphid with different nicotine extracts under different conditions as to strength and weather. In no case, in the writer's experience, were the plants injured, whereas the insect was destroyed in enormous numbers. The aphid is easily controlled by spraying with nicotine solutions

containing 40 per cent of nicotine at the rate of 1 part of the solution to from 1,000 to 2,000 parts of water, with whale-oil soap at the rate of 1 pound to 50 gallons of spray mixture. When only a few rose bushes require treatment the spray may be prepared in small amounts as follows: To 1 teaspoonful of 40 per cent nicotine solution add 1 to 2 gallons of water and one-half ounce of whale-oil soap. The soap should be shaved fine and dissolved in hot water.

There are on the market numbers of solutions containing less nicotine than the foregoing which may be used with good results with the addition of whale-oil soap, as advised, at the strength recommended by the manufacturers. If these are not obtainable, very good results may be accomplished by dissolving 1 pound of whale-oil soap or 2 pounds of common laundry soap in from 4 to 6 gallons of water. Wherever possible, however, the nicotine solutions should be used, as better results will be obtained.

This species, like practically all of the green aphides, can also be controlled by repeated applications of a forcible stream of cold water. Since the roses in California and some other localities are much subject to mildew, repeated use of this method has the disadvantage of increasing injury by this disease. In the case of the appearance of mildew, however, either through syringing with water or through the application of nicotine sulphate, this disease may be readily controlled by adding to the nicotine sulphate solution copper sulphate or blue vitriol at the rate of 1 pound to 50 gallons of water (approximately 1 ounce to 3 gallons). A solution of copper sulphate used at this strength and sprayed on the plants after the application of the water treatment is effective in controlling the mildew. Another common practice of florists for the prevention of mildew is to dust the plants immediately after sprinkling or watering with common flowers of sulphur.

In order successfully to fight this insect these sprays should be applied with a compressed-air sprayer (Pl. III) or bucket pump capable of creating a fine penetrating spray. These pumps can usually be purchased at the seed stores at from \$3.50 up to \$15. The nicotine solutions are also carried by most seed stores. Where a pump is not to be obtained much can be accomplished by dipping the infested twigs into a pail of the solution of nicotine.

From the experiments of the writer it is evident that this insect can be destroyed easily by the use of nicotine solutions of considerably less strength than have heretofore been used, but the treatment must be repeated at intervals to kill the aphides missed by former applications. With the different styles of pumps now on the market at low prices no one who cares for roses has the slightest excuse for allowing them to be injured by this insect.

TREATMENT IN THE GREENHOUSE.

For the treatment of the rose aphid as it occurs in greenhouses the nicotine solutions may be used, but at a lower strength than advised in the preceding paragraphs. Conditions vary somewhat, but it is believed that in most cases if the nicotine solution is used at the strength of 1 part to 2,000 of water it will not injure the rose plants if applied on a dark day or late in the afternoon so that the plants will not be exposed to reflected sunlight through the glass.

When greenhouses containing different forms of plants are syringed with a forcible stream of water or with neutral soaps of the castile or similar types for the red spider and other insects, the rose aphid and other green aphides will also be killed. The same is true in regard to fumigations with hydrocyanic-acid gas for other rose pests. Directions for the use of hydrocyanic-acid gas for the fumigation of greenhouses and cold frames are given in Circular No. 37 of the Bureau of Entomology. In the experience of Dr. A. F. Woods, the author of that publication, the young growth of roses is particularly sensitive and has been more or less injured in experiments in the use of this gas. This is particularly true of such varieties as "Perle des jardins," "Mermet," and "Bride."

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No. 91



Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
May 16, 1914.

COST AND METHODS OF CLEARING LAND IN THE LAKE STATES.

By HARRY THOMPSON, *Agriculturist*, and EARL D. STRAIT, *Scientific Assistant*
Office of Farm Management.

INTRODUCTION.

Practically the entire northeastern part of Minnesota and all of Michigan and Wisconsin were originally forest land. Nearly all the southern parts of Michigan and Wisconsin are now cleared except for scattering farm wood lots. At the present time large areas of undeveloped land are found in northeastern Minnesota and the northern half of Michigan and Wisconsin. In Table I the figures showing the area of improved and unimproved lands were taken from the census of 1910; the statistics regarding the area of merchantable timber land and of logged-off land and the land values were compiled from data obtained from State, county, and township officials, lumber companies, and other companies or individuals well informed on these matters. The figures obtained furnish a fairly close approximation to the actual acreage of merchantable timber and logged-off land in the three States mentioned.

A part of the logged-off land in the three States specified probably would give better returns if put into permanent forest, but there is much good agricultural land in nearly every county in which these investigations have been conducted which at the present time is not growing desirable timber and is an idle waste (fig. 1), giving no returns whatever. Because of the danger from fire, these waste areas form a menace to the communities.

At the present rate of cutting, most of the remaining merchantable timber will be cut within the next 25 years. This means that in many counties there will be a change from lumbering to farming.

NOTE.—This bulletin gives details of cost and methods of clearing land in the Lake States and is of special interest to settlers in the logged-off sections of Michigan, Wisconsin, and Minnesota.

TABLE I.—*Acreage of improved and unimproved lands, merchantable timber, and logged-off land and values of the improved and logged-off lands in the various counties of Michigan, Wisconsin, and Minnesota.*

State and county.	Acreage.				Value per acre.	
	Improved.	Unimproved.	Merchantable timber.	Logged-off.	Improved.	Logged-off.
Michigan:						
Alcona.....	38,037	399,723	3,000	327,700	\$40 to \$60	\$5 to \$15
Alger.....	5,634	583,157	375,000	125,000	30	6
Alpena.....	51,403	322,357	1,200	322,357	25	10
Antrim.....	78,810	225,190	16,000	179,190	60	10 to 15
Arenac ¹	55,571	183,789	.....	113,800	60	10
Baraga.....	9,344	577,536	297,280	240,256	75	7 to 25
Bay ¹	142,635	140,885	.....	45,100	100	15 to 25
Benzie.....	48,856	152,104	2,000	132,100	50	10 to 25
Charlevoix.....	61,587	201,463	16,000	175,400	40 up	10 up
Cheboygan.....	50,925	413,075	43,280	300,795	30	10
Chippewa.....	79,336	927,384	233,360	348,400	50 to 55	6 to 25
Clare ¹	53,921	318,559	.....	293,559	60	15
Crawford.....	10,701	357,299	15,000	320,000	35	8
Delta.....	42,932	705,228	150,000	450,000	40	10
Dickinson.....	8,342	488,298	174,397	269,846	75 to 100	3 to 25
Emmet.....	54,265	256,135	40,200	174,720	20 to 30	10
Gladwin.....	54,123	278,037	2,000	240,592	40	7 to 10
Gogebic.....	4,742	720,378	597,327	69,319	50 to 80	5 to 12
Grand Traverse.....	109,378	189,502	15,360	134,192	50	12
Gratiot ¹	248,899	121,661	.....	50,000	.....	.....
Houghton.....	35,921	616,239	217,200	299,040	50 to 75	10
Iosco ¹	40,735	324,065	.....	232,000	20 to 50	5 to 20
Iron.....	9,008	758,992	366,833	325,575	30 to 50	5 to 12
Isabella ¹	193,124	172,856	.....	122,800	60	10 to 15
Kalkaska.....	42,563	324,157	59,640	172,500	20 to 50	15
Kent ¹	365,717	184,683	.....	134,700	65	30
Keweenaw.....	1,236	353,324	253,324	50,000	15	5
Lake ¹	33,884	336,675	.....	296,700	30 to 50	10 to 15
Leelanau.....	83,812	132,508	7,000	89,300	30 to 70	15
Luce.....	7,926	580,874	125,000	225,000	50	6 to 20
Mackinac.....	21,118	647,042	173,440	374,400	40 to 60	5 to 15
Manistee.....	75,031	284,649	3,000	231,649	40	15
Marquette.....	23,041	1,173,759	500,000	550,000	25 to 50	8 to 15
Mason.....	100,925	215,235	2,000	144,000	50	12 to 15
Meosta ¹	159,794	205,646	.....	23,080	50	10 up
Menominee.....	64,590	611,250	138,338	372,912	50	3 to 15
Midland ¹	94,717	243,843	.....	174,800	75 to 100	10 to 15
Missaukee ¹	60,918	311,562	.....	211,500	20 to 50	5 to 20
Montcalm.....	266,401	196,959	3,000	175,000	60 to 100	15
Montmorency.....	17,506	341,534	42,200	161,500	35 to 70	3 up
Muskegon ¹	109,656	212,904	.....	152,900	50 up	10 up
Nevada ¹	166,072	378,568	.....	240,600	25 up	2.50 to 25
Oceana.....	151,782	195,738	8,500	179,900	50 up	10
Ogemaw.....	55,437	315,763	2,000	260,800	40 to 50	10
Ontonagon.....	11,992	841,128	510,000	300,000	25 to 50	3 to 10
Oscoda.....	129,303	239,977	1,760	215,900	50	20
Oseola.....	16,218	352,422	10,000	296,400	25 to 50	10 to 15
Otsego.....	27,627	310,293	70,840	196,500	20 to 40	8.50 to 15
Ottawa ¹	247,236	114,364	.....	75,200	60 to 70	30 up
Presque Isle.....	39,925	393,995	9,960	245,800	30 to 35	10
Roscommon.....	8,951	335,369	30,000	245,000	25 to 50	7.50 to 25
Saginaw ¹	304,738	225,182	.....	72,200	.....	.....
Schoolcraft.....	15,431	757,049	100,000	400,000	30 to 75	5 to 15
Wexford.....	79,044	290,236	33,960	226,000	25 up	5 to 12.50
All other counties ¹	8,561,259	3,304,621	.....	.....	.....	.....
Total.....	.....	.....	4,587,261	11,954,628	.....	.....
Wisconsin:						
Ashland.....	24,400	668,000	150,000	450,000	50	3 to 35
Barron.....	170,203	396,197	3,000	400,000	20 to 60	10 to 15
Bayfield.....	21,700	940,200	200,000	600,000	60 to 150	3 to 100
Burnett.....	56,600	493,800	15,000	265,000	50	10 to 20
Chippewa.....	198,000	468,900	46,800	315,600	40 to 50	12 to 20
Clark.....	151,900	627,600	1,250	625,000	50 to 100	6 to 10
Douglas.....	19,900	835,800	22,000	700,000	20 to 35	5 to 10
Dunn.....	245,100	311,100	1,000	300,000	20 to 35	5 to 10
Eau Claire.....	185,861	223,459	2,000	113,000	20 to 50	7 to 20
Florence.....	8,500	309,600	93,500	202,200	50	4 to 10
Forest.....	6,100	889,900	335,085	490,800	50	10
Iron.....	3,900	503,000	165,000	335,000	75 to 100	3 to 25
Langlade.....	47,800	512,200	240,000	250,000	25 to 60	3 to 20

¹ The only timber in the county is in farm wood lots.² Orchard land.

TABLE I.—*Acreage of improved and unimproved lands, merchantable timber, and logged-off land and values of the improved and logged-off lands in the various counties of Michigan, Wisconsin, and Minnesota—Continued.*

State and county.	Acreage.				Value per acre.	
	Improved.	Unimproved.	Merchantable timber.	Logged-off.	Improved.	Logged-off.
Wisconsin—Continued.						
Lincoln.....	33,550	543,730	203,000	307,000	\$40 to \$80	\$8 to \$20
Marathon.....	184,150	810,410	86,500	700,000	25 to 60	10 to 20
Marinette.....	79,474	826,126	210,000	575,000	20 to 60	5 to 10
Oconto.....	134,000	581,500	125,000	110,000	40 to 60	3 to 15
Oneida.....	17,700	558,900	37,000	485,000	30 to 60	5 to 12
Pepin.....	70,175	80,865	1,000	2,500	25	10
Polk.....	149,600	448,800	15,000	225,000	40	12
Portage.....	218,149	301,530	7,500	197,500	25 to 50	5 to 10
Price.....	23,100	795,500	180,480	500,000	25 to 60	6 to 15
Rusk.....	25,900	566,100	90,000	400,000	50 to 100	9 to 20
Sawyer.....	10,400	834,400	225,000	550,000	50	5 to 25
Shawano.....	170,200	370,900	211,600	185,000	30 to 40	8 to 10
Taylor.....	33,900	600,300	200,320	300,000	40 to 60	10 to 20
Vilas.....	4,600	528,500	85,000	350,000	30 to 60	5 to 12
Washburn.....	41,600	492,800	18,000	365,000	20 to 70	5 to 15
Waupaca.....	221,248	264,512	1,250	97,500	25 to 60	10 to 20
Wood.....	108,000	409,800	1,000	396,000	50 to 75	8 to 20
All other counties.....	9,243,896	7,060,800	(1)			
Total.....			2,972,285	10,792,100		
Minnesota:						
Aitkin.....	34,750	1,136,450	100,000	800,000	40 up	5 to 10
Anoka.....	101,575	192,000	1,200	110,000	30 to 90	15 to 30
Becker.....	178,892	684,468	200,000	450,000	30 to 60	10 to 30
Beltrami.....	33,253	2,413,000	500,000	1,350,000	20 to 60	6 to 15
Benton.....	108,847	150,000	22,500	110,000	35 to 100	15 to 30
Carlton.....	27,518	527,362	10,000	510,000	50 up	10 up
Cass.....	40,262	1,300,000	300,000	900,000	25 to 75	5 to 16
Chisago.....	104,670	168,600	15,000	112,000	20 to 50	10 to 20
Clearwater.....	40,000	612,000	60,000	400,000	20 to 40	5 to 15
Cook.....	1,568	957,152	450,000	2 350,000		
Crow Wing.....	51,989	624,491	165,000	410,000	20 to 30	10 to 15
Hubbard.....	55,699	557,400	75,000	400,000	20 to 30	3 to 5
Isanti.....	109,642	173,246	1,200	100,000	20 to 50	10 to 20
Itasca.....	13,636	1,733,600	510,000	1,050,000	40	10
Kanabec.....	37,370	304,400	18,000	278,000	15 to 100	10 to 30
Lake.....	2,381	1,341,000	500,000	600,000		
Mahnomen.....	24,123	341,967	95,000	200,000	30 to 60	10 to 30
Marshall.....	380,677	763,600	32,500	50,000		
Mille Lacs.....	48,438	324,682	30,000	283,000	35 to 100	15 to 30
Morrison.....	184,150	547,370	20,000	450,000	25 to 40	40 to 15
Otter Tail.....	592,598	712,362	250,000	200,000		
Pennington.....	136,735	252,000	None.	2 60,000		
Pine.....	64,768	839,552	125,500	640,000	50	8
Polk.....	643,946	622,614	10,000	2 100,000		
Red Lake.....	77,138	199,342	3,000	2 25,000		
Roseau.....	157,332	911,000	60,000	350,000	20 to 60	5 to 20
St. Louis.....	41,111	4,120,809	300,000	1,200,000	40 to 50	5 to 25
Sherburne.....	110,927	175,793	1,000	2 100,000	40 to 90	15 to 40
Wadena.....	69,703	274,617	40,000	180,000	20 to 40	8 to 15
All other counties.....	16,169,835	9,164,710				
Total.....			3,894,900	11,768,000		

SUMMARY.

Classification.	Michigan.	Wisconsin.	Minnesota.
	<i>Acres.</i>	<i>Acres.</i>	<i>Acres.</i>
Approximate land area.....	36,787,200	35,363,840	51,749,120
Improved land.....	12,832,078	11,907,606	19,643,533
Unimproved land.....	23,955,122	23,456,234	32,105,587
Merchantable timber.....	4,587,261	2,972,285	3,894,900
Logged-off land.....	11,954,628	10,792,100	11,768,000

¹ Wood lots only.² Large burns.³ Brush land.

The clearing and management of the logged-off lands is the most pressing problem in most of these counties. The object of the investigations conducted by the Office of Farm Management has been to obtain data from which to acquaint the public with the large areas of undeveloped land in these sections and the nature of the work necessary to make them available for agricultural purposes. A study has also been made of all the different conditions of clearing and the best methods practiced in the different sections, with the object of combining the best practices into a system or number of systems of clearing adapted to the region.



FIG. 1.—Characteristic stump land in the Lake region.

At the present time very little logged-off land that would make desirable farm land can be bought for less than \$15 to \$25 per acre. As the cost of clearing varies from \$20 to \$90 per acre, the cost of farm land cleared of stumps will run from \$35 to \$115 per acre, the average being about \$65. When the cost of other necessary improvements is added to this, it makes the ultimate cost of an improved farm higher than the price of equally as good a farm in many of the older, well-settled agricultural sections of the United States. The high price of the logged-off land and the high cost of clearing seriously retard its development.

The methods given in this bulletin, while extensively used, are not necessarily the best possible. There is plenty of room for improvement in all the methods now practiced.

METHODS OF CLEARING.

All methods of clearing have to deal with the removal of the stumps, brush, and second growth. In a few localities the second growth can be disposed of to charcoal and wood-extract companies, to mining companies (for use as ties and timbers), to wood-pulp mills, or for use as fuel for enough to pay for its removal. It usually does not pay, however, to haul the wood more than 4 or 5 miles. In most cases the second growth (fig. 2) has no value except as firewood for the use of the settler, and its removal must be considered an expense of clearing.



FIG. 2.—Typical logged-off land of the Lake region.

It is cheapest to cut the brush as soon after logging as possible. It should be cut close to the ground when in full leaf, heaped into compact piles, and burned as soon as it will burn well. The best time for burning is during the summer. On account of the danger of the fire spreading at this time, the local or State fire warden should be consulted and a permit obtained from him before any burning is attempted.

Some make a practice of harrowing or disking the ground immediately after burning and then sowing timothy seed. The following spring, as the frost leaves the ground, clover seed is added. Others sow all the grass seed in the spring. Where possible it is a good plan to leave the land in pasture or meadow several years before removing any stumps. (Fig. 3.)

On hardwood land the cost of removing green stumps is much more than that of removing similar stumps that have decayed for six or seven years. In the case of pine stumps growing in the heavier



FIG. 3.—Stump land that has been pastured for several years.

soils, the settling of the land and the heaving action of the frost gradually work the stumps out of the ground, so that the expense of removing them will be somewhat less where the land has been in grass several years. (Fig. 4.) A serious drawback to leaving the



FIG. 4.—Blasting stumps from land that has been in pasture for several years.

land in grass without stumping is the sprout growth. To keep down this sprout growth requires persistent work for several years. Sheep and goats have been used successfully in some localities, but the dairy herd has taken the place of nearly all the flocks and is considered more profitable.

In cultivating a field covered with stumps, it is impossible to use modern farm machinery efficiently. Stumps are removed (1) by explosives alone, (2) by explosives used in connection with stump pullers or block and line, (3) by stump pullers alone, and (4) by power machines.

EXPLOSIVES.

Explosives alone are used effectively and economically in all stumping operations on the heavier soils and for well-decayed hardwood stumps on the lighter soils. They have the advantages of thoroughly breaking up the stumps, of not requiring a large force of men for clearing operations or a large cash outlay at one time, and of enabling the work to be done quickly. The rather high cost of explosives when bought in small quantities and the fact that only experienced men should handle them are their chief drawbacks. Direct cooperative buying in wholesale lots will reduce materially the cost of the explosives.

Satisfactory instructions ¹ regarding the use of explosives are now published by practically all manufacturers. The chief faults of the average man in blasting stumps are his tendency to place the charge too shallow and his failure to put it under the center of resistance of the stump.

On most of the land-clearing operations in Michigan dynamite containing 40 per cent of nitroglycerin or its equivalent is used. In a few sections dynamite containing 20 to 30 per cent of nitroglycerin or its equivalent has been used with very satisfactory results. On the Pacific coast 20 per cent nitroglycerin dynamite or its equivalent is used almost exclusively. Dynamite containing the smaller percentages is cheaper, less dangerous to use, and does not pack the soil to such an extent as the stronger preparations. On the heavier soils the lower strength explosives will give just as good results pound for pound as the higher. The lower strengths act more slowly, with much less shattering, and have almost the same lifting force as those containing higher percentages of nitroglycerin.

It is commonly believed that dynamite with 60 per cent of nitroglycerin is twice as effective as that with 30 per cent and that that with 40 per cent of nitroglycerin has twice the effectiveness of 20 per cent. Tests by the United States Bureau of Mines ² have demonstrated

¹ Valuable information regarding the proper use of explosives in stumping may be found in the following publications:

McGuire, A. J. Land clearing. University of Minnesota Agricultural Experiment Station, Bulletin 134, 32 p., 21 fig., 1913.

Kadonsky, J. F. The use of explosives in clearing land. University of Wisconsin Agricultural Experiment Station, Bulletin 216, 19 p., 20 fig., 1911.

Thompson, Harry. Cost and methods of clearing land in western Washington. U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 239, 60 p., 25 fig., 1912.

² Hall, Clarence, and Howell, Spencer P. The selection of explosives used in engineering and mining operations. U. S. Department of the Interior, Bureau of Mines, Bulletin 43, 50 p., 3 pl., 7 fig., 1913.

that the propulsive or lifting force of 60 per cent "straight" nitroglycerin dynamite is only 18.7 per cent more than that with 30 per cent. On the other hand, its disruptive or shattering force is 42.5 per cent more. Carefully conducted field tests in stump blasting have shown that the propulsive or lifting effect of 40 per cent nitroglycerin dynamite is but little more than that of 20 per cent, while the disruptive or shattering effect of the 40 per cent is considerably more than that of the 20 per cent preparation. In stump blasting a high propulsive force and a comparatively low disruptive effect are desirable. For this reason ammonia dynamite (powders containing some ammonia and branded "extra") and powders containing no nitroglycerin, because of their slower action and consequent low



FIG. 5.—Capstan stump puller. This type requires an anchor stump from which all stumps within a radius equal to the length of the pulling cable can be pulled.

disruptive effect, are generally to be preferred to the straight nitroglycerin powders. In case the lower nitroglycerin powders or their equivalent are employed, No. 6 or stronger caps should be used.

STUMP PULLERS.

Two types of stump pullers are used—those that pull from the side, as the capstan (fig. 5), and the tripod type, which lifts the stump vertically (figs. 6 and 7).

THE CAPSTAN TYPE OF MACHINE.

The capstan type has the advantage that an acre or more of stumps can be pulled at a single setting. In pulling small stumps like scrub oak, jack pine, and certain kinds of hardwood, the saving in time is

quite an item. In pulling small, sound stumps considerable time is saved in not having to dig root holes, which are necessary when using a tripod type of machine. With large stumps which are partly decayed, this saving of time over that required in the use of the tripod type is about offset by the loss of time due to stumps breaking off.

When this occurs, each large root must be dug and pulled out separately. The capstan machine will work on steeper land than the tripod, though no machine will do very satisfactory work on a steep

hillside. By using the double and triple power arrangements of lines, the capstan machines will pull any white-pine stump in the Lake States. Many practical land-clearing operators using the capstan machines do not favor the use of the double or triple power in

connection with these machines because of the time lost in adjusting the blocks and hauling the extra cable. They prefer to use a small quantity of dynamite under the larger stumps to split and loosen them. With the tripod type of machine the use of dynamite to loosen the stump

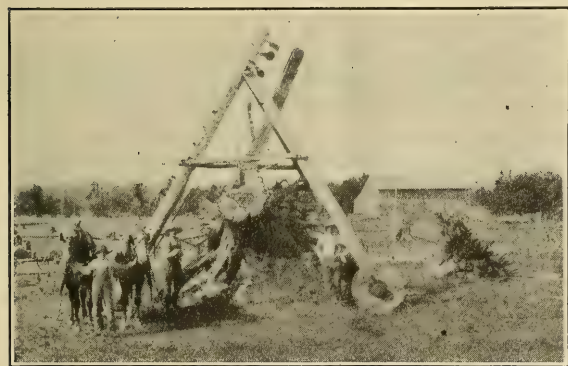


FIG. 7.—Another stump puller of the tripod type.

is unnecessary, because these machines are powerful enough to pull any white-pine stump.

THE TRIPOD TYPE OF MACHINE.

Many stumping contractors clearing white-pine land in Michigan use the tripod type of machine. Any stump pulls more easily when lifted vertically than when pulled from the side. No anchor stump

is required with this type. The vertical-lift machines are more powerful and seem to require less repairs than the average capstan machine. On the other hand, the machine must be moved for each stump, requiring four or five horses. Holes must be dug under the roots of each stump.

POWER MACHINES.¹

Power machines have been used to a limited degree throughout this region. On large tracts of land, with a good outfit and an efficient crew, the clearing probably can be done with a power machine as cheaply as and considerably faster than by any other method in use at the present time.

COST OF CLEARING LAND.

The cost of clearing land in the Lake States varies greatly. It runs from \$5 to about \$100 per acre. The cut-over jack-pine land is the cheapest to clear and green hardwood and unburned swamp land the most expensive. The cost of clearing depends on the following factors:

(1) The quantity of second growth and logs per acre: The cost of disposing of these runs from \$5 to \$25 per acre, and even higher, with an average of about \$10.

(2) The kind of stumps and the number of years since logging: All green hardwood stumps are very expensive to remove. Green birch and basswood are perhaps the most difficult. Most hardwoods decay so that they can easily be removed within 10 years from the time of logging, provided the sprout growth is not allowed to develop. Jack pine and hemlock will decay at about the same rate as hardwood. Scrub oak is more resistant to decay than the other hardwoods. White pine and Norway pine will not decay in 50 years. The cost of removing pine stumps from 5 years to 25 years after logging is practically the same.

(3) The size and number of stumps per acre: The number of white-pine stumps per acre varies from 10 to 100, with an average of about 45. Some hardwood lands have more than 400 stumps per acre. Some contractors taking work by the job count the stumps and then add 10 per cent to the number to cover those that were overlooked or burned close to the ground. It usually is more expensive to remove severely burned white-pine stumps than it is to remove a sound stump. For this reason any system of burning that will not burn the roots below plow depth does not reduce the cost of stumping. A pretty close approximation of the average number of stumps per acre may be obtained by counting the number of stumps on several sample acres. A circle of 117.8 feet radius contains an area of 1 acre. A rapid and convenient method is to stand on a stump and count all the stumps within 118 feet of it.

(4) Soil and topography: Where stump-pulling machines are used, the cost of stumping in sandy soils is less than in heavier soils. Where dynamite is used, the cost in heavier soils is less than in sandy soils. On many tracts the land was swampy at the time of the tree growth, and the rooting system was consequently shallow. After the tract shown in figure 8 was logged, fires burned off all the litter and most of the humus, leaving nearly all of the roots exposed. On many such areas a heavy team will tip out most of the stumps by a direct pull. For this reason this type of clearing is not usually expensive. (See "Tract No. 20," p. 22.) It is more expensive to pull stumps on steep land than it is on level land. It is more expensive to stump stony land than land free from stones, because the cleaning of the stumps is more difficult.

¹ See Thompson, Harry, Cost and methods of clearing land in western Washington, U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 239, 60 p., 25 fig., 1912, for use of power machines for land clearing.

(5) Size of area to be cleared and proximity to other clearings: Stump-pulling machines will usually reduce the cost of clearing, but it is not economical to buy one for the clearing of a small tract. Explosives cost considerably less when bought in large quantities. In a locality where much clearing is being done it may be possible to cooperate in the purchase of stump pullers and explosives, and experienced help can be hired cheaper in such a region.

Table II gives an approximate idea of the cost of clearing white-pine land in this region. Additional data of the conditions of clearing



Fig. 8.—Swampy lands of the Lake region that have been burned over, showing the shallow root-ing system.

on the 16 tracts summarized in this table, as well as details of the clearing of several additional tracts, are given in the pages which follow.

TABLE II.—*Approximate cost of removing stumps on 16 tracts of white-pine land, compiled from records kept during actual operations.*

Tract.	Acres.	Stumps.			Soil and subsoil.	Method.	Cost, including labor.				
		Number.	Average diameter (inches).	Average number per acre.			Pulling. ¹		Total.	Per acre.	Per stump, including disposal.
							Contract.	Actual.			
No. 1.....	40	2,000	20.2	50	Sandy.....	Explosive.....			\$925.20	\$23.13	\$0.463
No. 2.....	3	297	18-36	99	do.....	do.....			258.00	86.00	.86
No. 3.....	7	334		48	Clay.....	do.....			200.00	28.57	.60
No. 4.....	24.21	290	19.85	12	Sandy.....	Capstan.....	\$0.259		145.00	5.99	.50
No. 5.....	50	1,018	22	20	Sandy loam ²	do.....	.372		698.91	13.98	.686
No. 6.....	1	78	18.6	78	Sandy.....	do.....		.144	25.65	25.65	.329
No. 7.....	60	2,464	24.6	41	Clay.....	Tripod.....	\$0.32	.26	1,444.00	24.07	3.586
No. 8.....	30	2,464	24	82	Sandy loam.....	do.....	.19	.102	868.00	28.93	3.352
No. 9.....	30	2,000	28	67	do.....	do.....	.25	.105	710.00	23.67	3.355
No. 10.....	46	1,812	28.6	39	Silt and clay.....	do.....	.35	.32	1,283.82	27.91	3.71
No. 11.....		1,319	28.6		do.....	do.....		.465	1,063.87		3.806
No. 12.....	40	2,400		60	Sandy.....	do.....	.18	.14	768.00	19.20	3.32
No. 13.....	20	1,293	23.2	65	do.....	do.....	.387		500.00	25.00	3.387
No. 14.....	7.4	204	26.77	28	Sandy loam.....	do.....	.50	.563	184.93	25.06	.907
No. 15.....	40	3,600		90	Sandy.....	do.....	.25	.25	900.00	22.50	3.25
No. 16.....	35	1,050		35	do. ²	do.....	.333		700.00	20.00	.666

¹ The operation of "pulling" includes getting the stump out of the ground, cleaning the dirt from its roots, and leaving it where it will not settle back into the ground.

² Clay subsoil.

³ Tracts Nos. 7 to 13 and 15 were stumped by experienced contractors, who were well equipped and employed experienced men with heavy teams accustomed to the work. The average landowner can not safely figure on getting his stumps pulled for less than these contract prices.

TRACT NO. 1.

Tract No. 1 contained 40 acres of level land. The soil to root depth varied from medium to fine sand. The blasting was done in the spring of 1913 at a time when the ground was wet. The tract was logged 32 years before. Since that time it had been burned repeatedly, and there was no undergrowth. The tract averaged 4 or 5 small logs per acre. Of the stumps on the tract 16 per cent were so severely burned that it was necessary to partially dig the roots out and pull them with a team. The average number of stumps per acre was 50, of which 20 per cent were Norway pine and 80 per cent were white pine. The diameter of the stumps at the cut-off varied from 6 to 30 inches, the average being 20.2 inches.

The owners of this tract had recently purchased a capstan stump puller. With an inexperienced crew the cost of pulling and disposing of the stumps, as shown in Table III, was practically the same as with dynamite.

TABLE III.—*Cost of labor and material in clearing an acre of tract No. 1.*

Item.	Days employed.	Cost.	
		Per diem.	Total.
Blasting stumps:			
1 powder man.....	1	\$2.00	\$2.00
Dynamite, 75 pounds at 13 cents.....			9.75
Caps and fuse.....			1.13
Pulling roots and piling and burning stumps:			
3 men, 1 day each.....	3	1.75	5.25
1 man with team.....	1	5.00	5.00
Total cost per acre.....			23.13
Total cost per stump.....			.463

TRACT NO. 2.

Three acres of pasture land having a sandy soil, containing 297 white-pine stumps 18 to 36 inches in diameter, were blasted by the use of 1,200 pounds of powder containing no nitroglycerin. This is an average of 43 cents per stump, including the cost of labor for doing the powder work. The cost of piling and burning is equal to the cost of blasting, which makes an average of 86 cents per stump and approximates \$86 per acre.

TRACT NO. 3.

Seven acres containing 334 white-pine stumps upon pasture land having a clay soil were blasted, piled, and burned at a cost of \$200, an average of 60 cents per stump and \$28.57 per acre.

TRACT NO. 4.

Tract No. 4 contained 24.21 acres of level land having a sandy-loam soil within root depth and practically no stones. The outfit used was a capstan stump puller, with 200 feet of 1-inch cable on a drum and an additional length of 150 feet of 1-inch cable, giving the

machine a pulling radius of nearly 350 feet. The other tools used were 15 feet of 1¼-inch double-power cable, 14 feet of 1½-inch cable, shovels, axes, a bar, and a mattock.

The pine of the tract had been logged about 30 years ago. The hardwood had been cut off seven or eight years ago, except where noted. The hardwood stumps were so rotten that they were very easy to remove. The tract had been burned repeatedly since logging. Scarcely any vegetation or sod was left to retard the work of cleaning the soil from the stumps. There was a very scattering growth of poplar and bird cherry, averaging about 3 feet in height on the tract. Included in the 290 stumps were 76 "snags"—stumps that had been burned close to the ground, leaving the roots in the ground. These snags are fully as hard to remove as the average stump. The stumps were piled later in the year by means of a gin pole. Details as to the kinds and sizes of the stumps and particulars relative to the cost of stumping are given in Table IV.

TABLE IV.—*Stumps pulled and cost of labor and material used on tract No. 4.*

KINDS AND SIZES OF STUMPS.

Kind of stumps.	Diameter of stumps (inches).																Total number of stumps.
	4	6	8	10	12	14	16	18	20	22	24	26	28	30	34	36	
	Number of stumps.																
White pine.....		1		1	1	4	8	16	30	16	19	15	14	17	1	6	149
Norway pine.....						1	1	2	5	2	2	1					14
Beech.....		3	2	2	4												11
Maple.....	1	2	3	7	1	1			1								16
Hemlock.....		1	6	1	6	3											17
Birch.....		1			1												2
Scrub oak.....					1	1											2
Poplar.....				1													1
Green hard maple.....					1												1
Green white pine.....				1													1
Total.....	1	8	11	12	15	11	9	18	36	18	21	16	14	17	1	6	214
Number of snags.....																	76
Total for 24.21 acres.....																	290

LABOR AND MATERIAL USED IN STUMPING.³

Item.	Days employed.	Cost.	
		Per diem.	Total.
Crew:			
2 machine men, 6 days each.....	12	\$1.75	\$21.00
2 men to clean stumps, 6 days each.....	12	1.75	21.00
1 team and teamster.....	6	4.00	24.00
Use of machine.....	6	1.50	9.00
Piling and burning (estimated).....			70.00
Total.....			145.00
Average per acre.....			5.99
Average per stump.....			.50

¹ Average diameter of the 214 stumps, 19.85 inches.² Average number of stumps per acre, 12.³ Time of clearing, 6 days, July 28 to Aug. 4, 1913.

The average height of the pine stumps was 33 inches. The average number pulled each day was 48. The cost of pulling, cleaning, and tipping was 25.9 cents per stump. Dynamite had been used in stumping this land, but because of the loose nature of the soil it had proved too expensive.

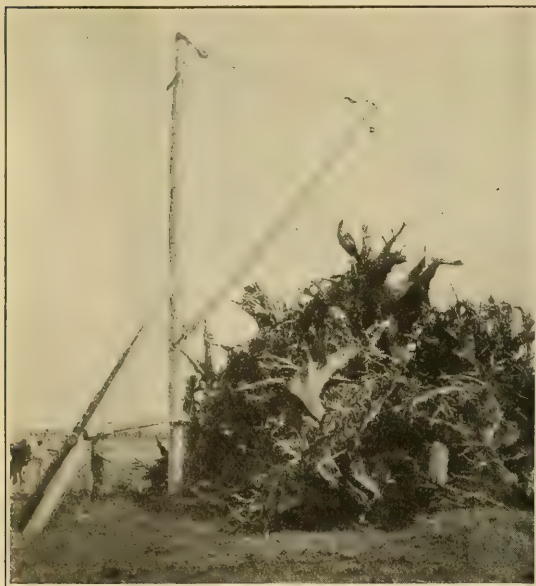


FIG. 9.—Device for piling stumps.

TRACT NO. 5.

Tract No. 5 contained 50 acres of very gently rolling pasture land with sandy-loam soil and clay subsoil. The outfit consisted of a capstan stump puller, shovels, axes, and bars. The stumps were piled by the device shown in figure 9. Details of the cost of removing

1,018 stumps from this field are given in Table V.

TABLE V.—Cost of stumping tract No. 5.

Item.	Days employed.	Cost.	
		Per diem.	Total.
Pulling stumps:			
1 man.....	45	\$1.75	\$78.75
1 man.....	3	1.75	5.25
1 man with team.....	45	4.50	202.50
Use of stump puller.....	45	1.50	67.50
Dynamite, 200 pounds, at 12½ cents.....			25.50
Caps and fuse.....			1.41
Piling and burning stumps:			
3 men with teams, 20 days each.....	60	4.50	270.00
1 man.....	20	1.75	35.00
Use of stump piler.....	20	.75	15.00
Total.....			698.91
Average per acre.....			13.98
Average per stump.....			.686
Average per stump for pulling.....			.372
Average per stump for piling.....			.314

The pulling was done in 45 days, an average of 23 per day. The average number of stumps per acre was about 20. This tract was logged 30 years ago. Fires had kept down all underbrush. All logs had been removed. The rooting system of the stumps was shallow. In burning, the stumps were placed about 50 in a pile. They were set on fire at night, and usually the following morning the unburned stumps were repiled. The sizes of 87 white-pine stumps measured

on this tract were as follows: 16-inch, 7; 18-inch, 12; 20-inch, 18; 22-inch, 17; 24-inch, 16; 26-inch, 10; 28-inch, 4; 30-inch, 2; 32-inch, 1. The average diameter was 22 inches and the average height 33 inches.

On a neighboring tract, similar in all respects, the stumps were pulled and cleaned under contract for 40 cents each. Here three men with a light team, using a capstan machine, pulled an average of 20 stumps a day. The man for whom the stumps were pulled under contract formerly used dynamite of 40 per cent strength and pulled the remaining roots with a team, using a block and line. He also tried heavy blocks and line. All these methods were found less satisfactory than a contract at 40 cents per stump. In piling stumps the device shown in figure 9 was used, and with the same crew an average of 50 stumps a day was piled.

TRACT NO. 6.

Tract No. 6 contained 1 acre of level land, having a loose, sandy soil. It was cleared in August, 1913. The outfit used was a capstan stump puller. At the time of tree growth this tract was wet; as a result the stumps were shallow rooted. The tract was logged about 35 years ago. Repeated fires since that time had burned off the litter until the roots of the stumps were well exposed, and there was practically no undergrowth or logs on the tract. The sizes of 62 white-pine stumps, selected at random and measured on this tract, were as follows: 12-inch, 4; 14-inch, 8; 16-inch, 9; 18-inch, 12; 20-inch, 11; 22-inch, 9; 24-inch, 9. The average diameter was 18.6 inches and the average number per acre was 78.

The low cost per stump of clearing this tract, as shown in Table VI, was due to the small size of the stumps and to the fact that the rooting system was very shallow. On this farm the actual cost of clearing over a hundred acres of land has been \$39.30 per acre. About 50 per cent of this land is as described above. The remainder is low, wet, sandy land with cedar, tamarack, and occasional white-pine or Norway-pine stumps. The average number of stumps per acre was about 12, and their average diameter was about 10 inches.

TABLE VI.—*Cost of clearing tract No. 6.*

Item.	Daysem- ployed.	Cost.	
		Per diem.	Total.
Pulling stumps:			
3 men.....	1	\$1.75	\$5.25
1 team.....	1	4.50	4.50
Use of stump puller.....	1	1.50	1.50
Piling and burning stumps:			
2 men.....	1.2	1.75	4.20
1 team.....	1.2	4.50	5.40
Repiling stumps (time estimated):			
2 men.....	.6	1.75	2.10
1 team.....	.6	4.50	2.70
Total per acre.....			25.65
Total per stump.....			.329

Because of the shallow rooting system and small size of the stumps, most of them could be pulled by a 2,800-pound team without the use of blocks and line. The stumps that could not be pulled by a team were split by a small charge of dynamite, and the remaining pieces were pulled out by a team. The second growth on this land consisted of poplar and bird cherry. Small logs were numerous. The various items entering into the cost of clearing were not kept separately. The superintendent said that they were approximately as follows:

To cut, pile, and burn brush, per acre.....	\$10. 00
To pile and burn logs, per acre.....	12. 00
To pull, pile, and burn stumps, per acre.....	17. 30
Total cost per acre.....	39. 30

TRACT NO. 7.

Tract No. 7 contained 60 acres, principally of heavy clay soil, in a few places having sandy-loam soil with a heavy clay subsoil 6 inches below the surface. The land was nearly free from stones and was gently rolling. The outfit used was a tripod stump puller. This tract had been logged 20 years before. All the stumps were white pine. There was no undergrowth or logs. The tract had been pastured several years and at the time of stumping was covered with a fairly good clover sod.

The sizes of 354 white-pine stumps selected at random and measured on this tract were as follows: 12-inch, 2; 14-inch, 2; 16-inch, 11; 18-inch, 28; 20-inch, 37; 22-inch, 35; 24-inch, 88; 26-inch, 65; 28-inch, 42; 30-inch, 21; 32-inch, 13; 34-inch, 6; 36-inch, 4. The average diameter was 24.6 inches. The average height was 36 inches. The total number of stumps pulled was 2,464, the average per day being 54. The average number per acre was about 41. Details of the cost are given in Table VII. The stumps on this tract were piled in the fall of the year and will be permitted to dry out for about two years before any attempt will be made to burn them.

TABLE VII.—*Cost of stumping tract No. 7.*

Item.	Days employed.	Cost.	
		Per diem.	Total.
Pulling, cleaning, and tipping stumps:			
2 men, 46 days each.....	92	\$1. 75	\$161. 00
2 men with team, 46 days each.....	92	4. 50	414. 00
Use of machine.....	46	1. 50	69. 00
Piling and burning (estimated).....			800. 00
Total.....			1, 444. 00
Average per acre.....			24. 07
Average per stump.....			. 586

The work of stumping this tract was difficult because of the nature of the soil and size of the stumps. It was done under contract by one of the largest stumping contractors in Michigan. All of the crew were experienced men. The contract price for pulling, cleaning, and tipping the stumps on this tract was \$788, or about 32 cents per stump. The actual cost was 26 cents. The average farmer or settler, even though he had the equipment, probably could not do the work as cheaply as it was done by this contractor.

TRACT NO. 8.

Tract No. 8 contained 30 acres of nearly level land with sandy-loam soil. The outfit used was a tripod stump puller. The total number of stumps pulled was 2,464. The average number pulled per day was 137. The average number per acre was about 82. The average diameter per stump was about 24 inches. This work was done under contract at 19 cents per stump for pulling, cleaning, and tipping. The actual cost was 10.2 cents, as shown in Table VIII. The low cost of stumping was largely due to the sandy nature of the soil and the fact that the stumping crew was experienced. These stumps were to be piled and burned later in the year.

TABLE VIII.—*Cost of stumping tract No. 8.*¹

Item.	Days employed.	Cost.	
		Per diem.	Total.
Pulling, cleaning, and tipping:			
2 men, 18 days each.....	36	\$1.75	\$63.00
2 men with teams, 18 days each.....	36	4.50	162.00
Use of machine.....	18	1.50	27.00
Piling and burning (estimated).....			616.00
Total.....			\$868.00
Average per acre.....			28.93
Average per stump.....			.352

¹ Tract stumped in the fall of 1912.

TRACT NO. 9.

Tract No. 9 contained 30 acres of nearly level land with sandy-loam soil. The outfit used was a tripod stump puller. The total number of stumps pulled was 2,000. The average number pulled per day was 134. The average number per acre was about 67. The average diameter per stump was about 28 inches. This work was done under contract at 25 cents per stump for pulling, cleaning, and tipping. The actual cost was 10.5 cents, as shown in Table IX.

TABLE IX.—*Cost of stumping tract No. 9.*¹

Item.	Days employed.	Cost.	
		Per diem.	Total.
Pulling, cleaning, and tipping:			
2 men, 15 days each.....	30	\$1. 75	\$52. 50
2 men with teams, 15 days each.....	30	4. 50	135. 00
Use of machine.....	15	1. 50	22. 50
Piling and burning (estimated).....			500. 00
Total.....			710. 00
Average per acre.....			23. 67
Average per stump.....			. 355

¹ Tract stumped in the summer of 1913.

The low cost of stumping was largely due to the sandy nature of the soil and the fact that the stumping crew was experienced. This work was done by the same contractor who stumped tracts Nos. 7 and 8. The stumps were piled and burned later in the year.

TRACT NO. 10.

Tract No. 10 contained 46 acres of nearly level silt-loam to clay-loam soil. In places the tract was very stony; round cobblestones predominated. The outfit used was a tripod stump puller. This tract had been logged 30 years before. The second growth and logs had been previously removed.

The sizes of 114 white-pine stumps selected at random and measured on this tract were as follows: 12-inch, 1; 18-inch, 2; 20-inch, 8; 22-inch, 7; 24-inch, 22; 26-inch, 9; 28-inch, 10; 30-inch, 12; 32-inch, 17; 34-inch, 9; 36-inch, 10; 38-inch, 1; 40-inch, 3; 42-inch, 1; 44-inch, 1; 48-inch, 1. The average diameter was 28.6 inches and the average height 36 inches. The total number of stumps pulled was 1,812. The average number pulled per day was 48. The average number per acre was 39. This work was done under contract at 35 cents per stump for pulling and cleaning. The actual cost of pulling and cleaning was 32 cents per stump, as shown in Table X.

TABLE X.—*Cost of stumping tract No. 10.*¹

Item.	Days employed.	Cost.	
		Per diem.	Total.
Pulling and cleaning stumps:			
2 men, 37½ days each.....	75½	\$1. 75	\$132. 12
1 man with team.....	37½	4. 50	169. 88
1 man with 3 horses.....	37½	5. 85	220. 84
Use of machine.....	37½	1. 50	56. 62
Tipping stumps (estimated at 3 cents each).....			54. 36
Piling and burning (estimated).....			650. 00
Total.....			1,283. 82
Average per acre.....			27. 91
Average per stump.....			. 71

¹ Tract stumped from June 27 to Aug. 12, 1913.

The work was done by an extensive stumping contractor. The stony ground made digging holes under the roots and cleaning the stumps expensive. The large size of the stumps made their removal costly. The stumps were to be piled later in the year by the use of a log jammer.

TRACT NO. 11.

The operation on tract No. 11 consisted of pulling 1,319 large white-pine and scattering hardwood stumps on silt-loam to clay-loam soil. In places this tract was very stony. The outfit was a tripod stump puller, the same as that used for tract No. 10, which was adjacent. It had been logged 30 years before. All the second growth and logs had been removed. The average size of the stumps was slightly larger than those on tract No. 10. The average number of stumps pulled per day was 37, and the cost was as shown in Table XI.

TABLE XI.—*Cost of stumping tract No. 11.*¹

Item.	Days employed.	Cost.	
		Per diem.	Total.
Pulling and cleaning stumps:			
2 men, 35.6 days each.....	71.2	\$1.75	\$124.50
1 man with team.....	35.6	4.50	160.20
1 man with 3 horses.....	35.6	5.85	208.26
Use of stump puller.....	35.6	1.50	53.40
Dynamite (40 per cent strength), 500 pounds, at 13 cents.....			65.00
Caps and fuse.....			2.51
Piling and burning (estimated).....			450.00
Total.....			1,063.87
Average per stump.....			.806

¹ Time of stumping, Aug. 12 to Sept. 26, 1913.

A small charge of dynamite was placed under the larger stumps in order to split and loosen them. In commenting on the use of dynamite here, the contractor said: "This is the only job in my seven years of stumping where it would pay to use dynamite under nearly every stump." The owner of this tract had previously used dynamite in stumping on his land.

TRACT NO. 12.

Tract No. 12 contained 40 acres of nearly level land with sandy-loam soil. The outfit was the same as for tract No. 11. The total number of stumps pulled was 2,400. The total number of stumps per acre was 60. The average number of stumps pulled per day was 100. The stumps averaged somewhat smaller than in the two preceding tracts, and the soil was sandy loam and free from stones. This work was done at a contract price of 18 cents per stump for pulling, cleaning, and tipping. The actual cost was 14 cents per stump, as shown in Table XII.

TABLE XII.—*Cost of stumping tract No. 12.*¹

Item.	Days employed.	Cost.	
		Per diem.	Total.
Pulling, cleaning, and tipping stumps:			
2 men, 24 days each.....	48	\$1. 75	\$84. 00
2 men with teams, 24 days each.....	48	4. 50	216. 00
Use of machine.....	24	1. 50	36. 00
Piling and burning (estimated).....			432. 00
Total.....			768. 00
Average per acre.....			19. 20
Average per stump.....			. 32

¹ Stumped in the spring of 1913.

TRACT NO. 13.

Tract No. 13 contained 20 acres of practically level pasture land having a sandy, and in places a gravelly, surface soil. The subsoil

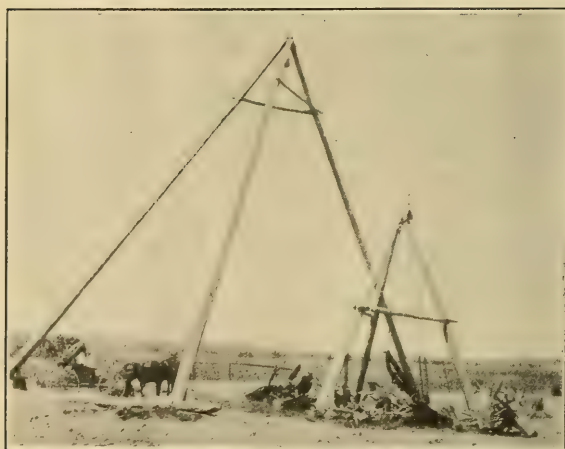


FIG. 10.—Tripod stump piler (at left) and tripod stump puller (at right).

was generally below root depth. This land had been logged 25 years before. There were no logs or underbrush. The outfit used was a tripod stump puller.

Stumps to the number of 1,293 were pulled, piled, and burned at a contract price of \$500, or 38.7 cents per stump. By means of the tripod piler shown in figure 10 all these stumps

were put into four piles. The stumps were pulled in November, 1912.

The sizes of 98 white-pine stumps selected at random and measured on this tract were as follows: 12-inch, 6; 14-inch, 8; 16-inch, 8; 18-inch, 5; 20-inch, 10; 22-inch, 16; 24-inch, 16; 26-inch, 11; 28-inch, 5; 30-inch, 8; 32-inch, 2; 34-inch, 1; 38-inch, 2. The average diameter was 23.2 inches.

Several other owners in this neighborhood had contracted to have stumps pulled, cleaned, and tipped for 25 cents each. The general clearing conditions on these contracts were the same as for tract No. 10.

TRACT NO. 14.

Tract No. 14 contained 7.4 acres of very gently rolling pasture land, having a loose, sandy-loam soil. The outfit used was a tripod

machine mounted on two wheels. This tract had been logged 45 years before. There were no logs or underbrush.

The sizes of 98 white-pine stumps selected at random and measured on this tract were as follows: 16-inch, 7; 18-inch, 10; 20-inch, 3; 22-inch, 9; 24-inch, 15; 26-inch, 14; 28-inch, 8; 30-inch, 6; 32-inch, 7; 34-inch, 4; 36-inch, 6; 38-inch, 3; 40-inch, 1; 42-inch, 4; 48-inch, 1. The average diameter was 26.77 inches.

The high cost of stumping this tract, shown in Table XIII, was principally due to the inexperience of the contractor and crew and to the fact that only one light team was used. The contract price for pulling, cleaning, and tipping the stumps was 50 cents each. The actual cost was 56.3 cents. The owner of the tract was utilizing the roots for fuel. The total number of stumps was 204 and the number per acre 28. The number pulled per day was 15.

TABLE XIII.—*Cost of stumping tract No. 14.*¹

Item.	Days employed.	Cost.	
		Per diem.	Total.
Pulling, cleaning, and tipping:			
1 boy.....	13 $\frac{1}{4}$	\$1. 00	\$13. 25
1 man.....	13 $\frac{1}{4}$	1. 75	22. 19
1 man with team.....	13 $\frac{1}{4}$	4. 50	59. 62
Use of machine.....	13 $\frac{1}{4}$	1. 50	19. 87
Piling and burning (estimated).....			70. 00
Total.....			184. 93
Average per acre.....			25. 05
Average per stump.....			. 907

¹ Time of stumping, July 19 to Aug. 8, 1913.

TRACT NO. 15.

Tract No. 15 contained 40 acres of very gently rolling land, having a sandy soil. The clearing was done in the spring of 1912. The outfit consisted of a tripod stump puller, two teams, and five men. This outfit and crew pulled 2,132 stumps in 20 $\frac{1}{2}$ days, an average of 104 stumps per day. This tract had an average of 90 stumps per acre, of which 20 were Norway pine and 70 were white pine.

The clearing was done at a contract price of \$30 an acre. The price included the delivery of the Norway-pine stumps to a turpentine plant 3 miles distant from the tract, the hauling of nearly one-third of the white-pine stumps to build fences, and the burning of the remainder of the white-pine stumps. The Norway-pine stumps had been burned to the surface of the ground on nearly 10 acres of this tract. A total of 60 cords of Norway-pine stumps was delivered at the plant. The price received was \$5 per cord of 4,000 pounds. It took an average of 10 Norway-pine stumps to the cord. Two cords of stumps per acre were obtained. After deducting the amount received for the stumps, the net cost of clearing the tract was \$900,

or \$22.50 per acre. The contractor still considers \$30 a fair price, but owing to circumstances and bad weather wages were not made upon this work.

In another case in this neighborhood the owner of 640 acres of land gave all the Norway-pine stumps on it for the clearing of 15 acres ready for the plow.

TRACT NO. 16.

On a tract of 35 acres of nearly level land, having a sandy-loam surface soil and a clay subsoil, which had been logged 30 years before, 1,050 white-pine stumps, averaging 26 inches in diameter, were pulled with a tripod machine at a contract price of $33\frac{1}{2}$ cents per stump for pulling, cleaning, and tipping.

TRACT NO. 17.

On another tract of 105 acres of nearly level land, having a sandy-loam surface soil and a clay subsoil averaging 18 inches below the surface, which had been logged 25 to 40 years before, 7,000 white-pine stumps, averaging 22 inches in diameter, were pulled with a tripod machine at a contract price of 25 cents per stump for pulling, cleaning, and tipping. These stumps were hauled into fence rows for 18 cents per stump, contract price.

TRACT NO. 18.

On a tract of 10 acres of gently rolling land having a sandy and gravelly loam surface soil and in places a clay subsoil, which had been logged 25 years before, 600 white-pine stumps, averaging 18 inches in diameter, were pulled with a tripod machine at a contract price of 30 cents each for pulling, cleaning, and tipping.

TRACT NO. 19.

On an adjoining tract of 16 acres, with soil the same as in tract No. 18, and using the same outfit, 330 stumps were pulled, cleaned, and tipped for 30 cents each. The contractor took both jobs at a flat rate of 30 cents per stump.

TRACT NO. 20.

Tract No. 20 contained 18 acres of cedar-swamp land that had been very severely burned in 1908 and 1911. The soil varied from a clay loam to a heavy clay. Practically all the roots had been burned off. The stumps rested on top of the ground. One horse could easily pull nearly every stump on this tract. The few stumps that were too firmly rooted to be pulled by a horse were loosened by the use of dynamite. The number of trees and stumps per acre on adjoining similar tracts was about 300. The stumping and part of the piling was done from July 15 to October 1, 1912. The remainder of the piling and all of the burning was done after April 12, 1913. The work of clearing was thorough. The details of cost are shown in Table XIV.

TABLE XIV.—*Cost of labor and material used in clearing tract No. 20.*

Item.	Days employed.	Cost.	
		Per diem.	Total.
Stumping and piling:			
1 man as laborer and driver.....	60	\$1. 75	\$105. 00
1 man as laborer and powder man.....	60	1. 75	105. 00
1 horse.....	60	1. 25	75. 00
Total labor cost.....			285. 00
Dynamite (40 per cent strength), 50 pounds, at 20 cents.....			10. 00
Fuse and caps.....			. 75
Burning stumps and completing clearing:			
1 man.....	18	1. 75	31. 50
1 man with team.....	18	4. 25	76. 50
Total.....			403. 75
Average cost per acre.....			22. 43

This swamp clearing is typical of the cost of clearing much of the severely burned swamp land of Cheboygan and Presque Isle Counties, Mich.

DISPOSAL OF STUMPS AFTER PULLING.

Where medium-sized stumps have been well blasted the problem of stump disposal is relatively simple. It is considered cheaper to start several small, conveniently located fires in the holes made by blasting the stumps and then haul the remaining pieces to these fires than it is to build a few large piles and not set them on fire until all the stumps are piled. Where the stumps have been pulled by a stump puller without the use of powder the problem of disposal is more difficult. The general opinion throughout this region is that the cost of disposal practically equals the expense of pulling. All data secured seem to verify the accuracy of this estimate. In the early days of clearing, the stumps were hauled into rows to serve as fences. At the present time very few such fences are being built. The usual contract price for hauling stumps into fences is 15 to 18 cents each.

PILING STUMPS.

Large stumps are very hard to pile. Some owners split the stumps by the use of a small charge of dynamite placed either in a hole bored into the base of the stump or in a notch chopped between two prominent roots. Often the heart of the stump is sufficiently decayed so that the charge may be placed in it. A small quantity of dynamite used in this manner will usually split the stump as well as a much larger charge would have done before the stump was pulled.

By using a tripod, such as is shown in figure 10, with legs 40 or 45 feet long and equipped with a double block and 150 feet of half-inch cable, the stumps can be piled 25 or 30 feet high. This tripod was used on tract No. 13. Another good method of piling is to use

a piler with a swinging boom, as shown in figure 9. The mast of this piler is 30 feet high and the swinging boom 25 feet long. In using this boom piler the mast is set so that it leans slightly toward the pile. This causes the boom to swing to the center each time. This piler was used in clearing tract No. 5. Dropping stumps into a fire by means of piling devices is impracticable, because the heat soon becomes so intense that the piling operations must be abandoned.

The work of piling stumps could be hastened materially if some satisfactory tripping device could be used. The usual self-tripping tongs and rope trips frequently catch on projecting roots and drop the load before it is at the desired position.

OTHER WAYS OF DISPOSING OF STUMPS.

In the past a considerable number of Norway-pine stumps have been used by turpentine manufacturers for distillation. The present low price of turpentine and naval stores has made the distillation of Norway-pine stumps unprofitable, and none of the turpentine plants are now in operation. The white-pine stump contains too small a quantity of the properties of the Norway-pine stump to make it of any value.

SUMMARY AND SUGGESTIONS.

There are approximately 11,954,628 acres of logged-off land in Michigan, 10,792,100 acres in Wisconsin, and 11,768,000 acres in Minnesota. A large part of this area will make good agricultural land if cleared and properly managed. In many localities poor methods make the clearing of this land unprofitable. Cutting and burning the second growth pasturing for several years, and keeping down all sprout growth is the most economical method of handling all logged-off lands before stumping them. Explosives play an important part in clearing land. On the heavier soils dynamite, with 20 to 30 per cent of nitroglycerin or its equivalent, is to be preferred. Cooperative buying in large quantities is recommended. Stump pullers reduce the cost of stumping on lighter soils. On the heavier soils the difference between the cost of clearing by explosives and by the use of stump pullers is very slight.

The cost of clearing the better grade of white-pine logged-off land will average \$10 per acre for disposing of the brush and \$25 to \$30 per acre for disposing of the stumps, making the cost of clearing \$35 to \$40 per acre. Some green hardwood lands and unburned swamp lands will cost as much as \$100 per acre. Some of the poorer jack-pine lands can be cleared for \$5 per acre or less.¹ The cost of disposing of the stumps after pulling practically equals the cost of pulling.

¹ Those contemplating farming the jack-pine lands are urged to study Smith, C. Beaman, Clover farming on the sandy jack-pine lands of the North, U. S. Department of Agriculture, Farmers' Bulletin 323, 24 p., 1 fig., 1908.

A tripod or a boom piler is recommended to facilitate piling and burning.

The settler with little capital and without experience who expects to make a farm out of a tract of logged-off land will find his problem a most trying one. The experiences of those who have attempted it are not encouraging. The man who starts farming with even 10 acres of his farm cleared will be much more likely to succeed than the man who begins on a tract covered with second growth and stumps. The former will have land on which to grow hay and other crops the first year. He can devote his extra time the first three or four years to the disposal of the second growth on the remainder of his tract. By seeding this, he will increase the area of his pasture or hay land materially and will be employing the best preparatory means of reducing the cost of stumping later. The settler should not forget that the cheapest and best land clearing is always done by experienced men with proper equipment.

For these reasons it is recommended that, in all localities where land companies are selling lands to settlers, no tract of land be sold unless it contains at least 10 acres of land cleared ready for the plow.

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DESTRUCTION OF GERMS OF INFECTIOUS BEE DISEASES BY HEATING.

By G. F. WHITE, M. D., Ph. D., *Expert, Engaged in the Investigation of Bee Diseases.*

INTRODUCTION.

To reduce the losses due to bee diseases beekeepers have often employed heat in one form or another. The direct flame has been used in scorching or burning the inside of hives that have housed infected colonies. Before being fed back to bees honey is often heated for the purpose of destroying the germs of bee diseases, should any be present. Heat is used in the rendering of wax and in the making of comb foundation. It is natural and very appropriate, therefore, that beekeepers should inquire about the amount of heating that is necessary to destroy the germs that produce diseases among bees.

As no work had been done to determine the facts relative to this question with any degree of accuracy, the writer has performed during the last two years a number of experiments for the purpose of ascertaining them. Of these experiments 55 are summarized in the three tables included in this paper. It may be of interest to beekeepers to know in a general way how these experiments were made. A brief description of the methods used will serve also to make the tables more readily understood. An aqueous suspension of larvæ sick or dead of the disease is made and placed in a small glass tube. This tube is immersed in water of the temperature desired in the heating. After the germ-containing material is heated in this way it must be tested to determine whether or not the germs have been destroyed. In the case of American foul brood this can be done by inoculating a suitable artificial medium with the heated material and observing the presence or absence of growth of *Bacillus larvæ*, the germ of this disease. As there is no artificial medium now known suitable for cultivating the infecting agent of either European foul brood, sacbrood,

NOTE.—This paper is of interest to beekeepers in all parts of the United States; it was read before the New York State Beekeepers' Association, February 10, 1914, at Ithaca, N. Y.

or Nosema disease, healthy colonies of bees must be inoculated in making the test in case of these diseases. This is done by feeding the bees the heated germ-containing material in sirup. If the disease is produced by this feeding, naturally the infecting agent has not been destroyed by the heating; but if the disease is not produced, it virtually has been destroyed by it. By repeated experiments of this kind in which the temperature used in the heating is varied, the minimum temperature at which any virus is killed can be determined. As will be seen from the tables, 13 experiments for European foul brood, 22 for sacbrood, and 20 for Nosema disease were made in which healthy colonies were inoculated with heated germ-containing material from these three diseases, respectively. In the last disease the stomachs from diseased bees furnished the germ-containing material for heating and feeding. In these experiments the temperature was maintained for 10 minutes as a rule.

DISEASES OF THE BROOD OF BEES.

Nearly a century and a half ago the name "foul brood" was used for a destructive brood disorder of bees, and for almost a century later it was apparently the custom to diagnose as foul brood any destructive disease of the brood. About half a century ago beekeepers began to note that all of the brood diseases are not the same. They began, therefore, to write of different forms of foul brood. At the present time it is known that there are at least three infectious diseases of the brood of bees. All of these diseases are more or less destructive, and it is quite likely that each of them has now and then been diagnosed as foul brood. In America these brood diseases are now known as European foul brood, American foul brood, and sacbrood.

EUROPEAN FOUL BROOD.

In European foul brood death occurs early, the larvæ dying usually before the time for cell capping. There is no viscosity (ropiness) to the decaying larvæ as a rule, and no pronounced odor present.

Numerous samples of this disease have been examined from the United States, and some from Canada. Its presence also in England, Germany, Switzerland, and Denmark is strongly suggested by written reports from these countries. It is very probable that the disease has a much wider geographical distribution than these facts indicate.

Two years ago the fact was demonstrated that the germ causing European foul brood is the microorganism to which the name *Bacillus pluton* is given. In a paper¹ announcing the fact it was stated that the studies then made indicated that the germ is easily killed by heat. This belief has been confirmed by further experiments.

¹ White, G. F., 1912. The Cause of European Foul Brood. U. S. Dept. Agriculture, Bureau of Entomology, Cir. No. 157.

Table I gives a brief summary of 13 inoculation experiments performed for the purpose of determining approximately the amount of heating necessary to destroy the germ of European foul brood.

TABLE I.—*A summary of the experiments made to determine approximately the minimum amount of heating necessary to destroy the germ causing European foul brood.*

Dates of inoculation.	Temperature.	Time of heating.	Results of inoculation.
	^{° C.}	<i>Min.</i>	
Sept. 12, 1912	75 to 80	10	No disease produced.
Do.	65 to 70	10	Do.
Sept. 23, 1912	64 to 66	10	Do.
Oct. 12, 1912	64 to 65	10	Do.
Oct. 1, 1912	62 to 63	10	Do.
Oct. 8, 1912	62 to 63	10	Do.
Oct. 10, 1912	62 to 63	10	Disease produced.
Oct. 4, 1912	61 to 62	10	Do.
Aug. 8, 1913	60	20	Do.
Sept. 3, 1912	60	10	Do.
Sept. 20, 1912	58 to 60	10	Do.
Sept. 28, 1912	57 to 60	20	Do.
Sept. 20, 1912	55 to 56	10	Do.

It will be observed by an inspection of Table I that European foul brood was produced in every instance where healthy colonies were fed disease material which had been heated for 10 minutes at temperatures below 63° C. (145.4° F.), but that no disease was produced when temperatures higher than 63° C. (145.4° F.) were used for the same length of time. The minimum temperature that can be used, therefore, in destroying the germ of European foul brood, if it is applied for 10 minutes, lies somewhere between 60° C. (140° F.) and 65° C. (149° F.), being near 63° C. (145.4° F.).

AMERICAN FOUL BROOD.

American foul brood is the disease of the brood of bees that is best known to beekeepers and is the one the presence of which they have been able to recognize most easily. In this disease the larvæ usually die after the cells containing them are capped. The disease is characterized especially by the marked viscosity (ropiness) manifested by the decaying larvæ that are dead of the disease. The pronounced odor noticeable within hives housing colonies affected by this disease, especially in its later stages, is another well-known characteristic.

This disease is very widely distributed geographically. Samples of it have been received from many localities in the United States, from Switzerland, New Zealand, Germany, England, and France, and it is very probable that it has a much wider geographical distribution even than is indicated by these facts.

Until seven years ago the cause¹ of American foul brood was not known. At that time the fact was demonstrated positively that the

¹ White, G. F., 1907. The Cause of American Foul Brood. U. S. Dept. of Agriculture, Bureau of Entomology, Cir. No. 94.

germ causing the disease is the one to which the name *Bacillus larvæ* is given.

The facts obtained to date are too meager to justify anything more than a general statement regarding the minimum amount of heating that can be employed in rendering material containing the germ of American foul brood noninfectious. Taking rather wide limits, it may safely be said that the minimum temperature at which this can be done, if the temperature is applied for 10 minutes, lies somewhere between 90° C. (194° F.) and 100° C. (212° F.). It seems quite probable, indeed, that a temperature less than 98° C. (208.4° F.) will suffice if applied for 10 minutes. When 100° C. was used the spores of *Bacillus larvæ* were killed in less than five minutes.

SACBROOD.

Observant beekeepers have for many years noted the presence of dead brood which seemed to them to be different from that dead of foul brood. Some were inclined to believe that the disease was an infectious one; a larger number apparently were disposed to ascribe the trouble to such causes as an unsatisfactory queen, starvation, and the like. This brood disease has been recently demonstrated to be an infectious one, and the name "sacbrood" has been given to it. Larvæ that die of this disease do so almost invariably after the time of cell capping. The most characteristic symptom of the disease is the saclike appearance of the dead larvæ when they are removed from the cell. This fact suggested the name "sacbrood" for the disease.

Sacbrood is frequently met with. Its presence has been diagnosed by Dr. A. H. McCray and the writer in 367 samples received from 44 States of the Union and in 13 samples received from Canada. Reports from England, Switzerland, and Australia indicate strongly that this disease exists in these countries also. It is very probable that it has a much wider geographical distribution than is shown by these facts.

More than a year ago it was again the writer's fortune to determine the cause of another brood disease. Unlike the cause of either European foul brood or American foul brood, the infecting agent causing sacbrood has not yet been seen. It was demonstrated, however, that the infecting agent in this disease passes through the pores of earthenware filters. For this reason the cause of sacbrood is spoken of as a filterable virus.

In a paper¹ announcing the cause of sacbrood the statement is made that the germ causing the disease is destroyed by a comparatively small amount of heat. This belief is confirmed by the results of the experiments summarized in Table II.

¹ White, G. F., 1913. Sacbrood, a Disease of Bees. U. S. Dept. of Agriculture, Bureau of Entomology, Cir. No. 169.

TABLE II.—*A summary of the experiments made to determine approximately the minimum amount of heating necessary to render sacbrood material noninfectious.*

Dates of inoculation.	Temperature.	Time of heating.	Results of inoculation.
	^{° C.}	<i>Minutes.</i>	
July 27, 1912	95 to 100	2	No disease produced.
Aug. 8, 1912	95 to 100	2	Do.
Aug. 29, 1912	75 to 80	10	Do.
Sept. 5, 1912	65 to 70	20	Do.
Sept. 3, 1912	55 to 60	20	Do.
Aug. 26, 1913	80	15	Do.
Do.	75	15	Do.
Do.	70	15	Do.
Do.	65	15	Do.
Do.	65	15	Do.
Sept. 2, 1913	65	15	Do.
Sept. 3, 1913	60	20	Do.
Sept. 9, 1913	60	15	Do.
Sept. 10, 1913	60	15	Do.
Sept. 17, 1913	60	10	Do.
Sept. 10, 1913	58	10	Do.
Sept. 17, 1913	58	10	Do.
Sept. 18, 1913	57	10	Sacbrood produced.
Sept. 9, 1913	55	20	Do.
Sept. 10, 1913	55	10	Do.
Sept. 17, 1913	55	10	Do.
Aug 6, 1913	50	30	Do

From Table II it will be observed that when larvæ dead of sacbrood were heated 10 minutes at a temperature of 57° C. (134.6° F.) or less and then fed to a healthy colony, sacbrood was produced; if, on the other hand, the dead larvæ used in making the feeding were heated to 58° C. (136.4° F.) or higher, the disease was not produced. The conclusion to be drawn from these experiments is that the minimum temperature, when maintained for 10 minutes, at which the infecting agent causing sacbrood is destroyed lies somewhere between 55° C. (131° F.) and 60° C. (140° F.), being near 58° C. (136.4° F.).

DISEASES OF ADULT BEES.

Very little is known about the diseases of adult bees. Many names have been used for the purpose of designating them, but the number of such diseases is probably small. There is only one adult disease that can be diagnosed at present by laboratory methods. This one is the Nosema disease.

NOSEMA DISEASE.

Fifty-seven years ago Dr. Dönhoff made a more or less brief study of a disease of adult bees in Germany. He observed that the stomach was the organ that was primarily affected. By feeding to healthy colonies in sirup the crushed stomachs from affected bees Dönhoff demonstrated that the disease could be transmitted to healthy colonies. It was therefore infectious.

The work by Dönhoff had been practically forgotten, apparently, when Zander,¹ of Erlangen, Germany, five years ago observed the

¹ Zander, E., Aug., 1909. Tierische Parasiten als Krankheitserreger bei der Biene. Münchener Bienenzeitung.

presence of a disease among adult bees. From the evidence at hand it seems most probable that the disorder encountered by Dönhoff and the one encountered by Zander are one and the same disease.

Aside from rediscovering the disease Zander has identified the germ causing it as a protozoan (a one-celled animal parasite) and has given to it the name *Nosema apis*. For the disease he has used the name "Nosema Seuche." This is an appropriate one, as it suggests somewhat the nature of the disease. The name "Nosema disease," which the writer suggests as the common name for this disease, is, it will be observed, only a translation of the German name used by Zander.

The germ *Nosema apis* gains entrance to the body of the bee by way of the alimentary canal. In the walls of the stomach the growth and multiplication of the parasite take place to an enormous extent, causing the abnormal appearance manifested by the organ. When the disease reaches an advanced stage the stomach is white and fragile and reveals upon a microscopic examination the presence of the parasite in very large numbers. In the spring of the year, especially, many weak colonies show upon examination a high percentage of Nosema-infected bees. Quite often, indeed, in the examinations that have been made of such colonies, 50 to 90 per cent of the bees in samples taken from them were found to be infected with the parasite. It is an interesting and important fact that a very large number of colonies which are strong and apparently doing well are found upon examination to contain at least a small percentage of Nosema-infected bees.

Nosema apis has a very wide geographic distribution. It has already been encountered in Germany by a number of investigators; it has been found in Australia, Switzerland, and England. The writer has found it in samples of bees received from 27 different States in the United States and in two samples of adult bees from Canada.

From the facts gathered it would seem that many of the cases called "spring dwindling" by the beekeepers are caused, in part at least, by *Nosema apis*. This statement is not by any means to be interpreted as saying that Nosema disease and spring dwindling are always the same.

It has been demonstrated experimentally that colonies can be weakened and killed by feeding to them material containing *Nosema apis*. For this and other reasons it seems certain that the disease causes a loss to apiaries, but, for want of sufficient data, the extent of such loss can not now be estimated at all definitely. From the facts at hand one is justified in at least drawing the conclusion that Nosema infection in a colony tends to weaken the colony. *Nosema apis* is therefore a germ in which the beekeeper is economically interested.

For the purpose of determining approximately the minimum amount of heating that is sufficient to destroy the germ *Nosema apis* the inoculation experiments summarized in Table III were made.

TABLE III.—Summary of experiments in which the germ, *Nosema apis*, was heated and fed to healthy colonies.

Dates of inoculation.	Temperature used in heating.	Time of heating.	Results of inoculation.
	° C.	Minutes.	
Oct. 29, 1912	95 to 100	5	No <i>Nosema</i> infection produced.
Nov. 12, 1912	95 to 100	5	Do.
Oct. 29, 1912	80	20	Do.
Nov. 9, 1912	80	10	Do.
Nov. 11, 1912	68 to 70	10	Do.
Do.	68 to 70	10	Do.
Nov. 12, 1912	65	20	Do.
Jan. 8, 1913	65	10	Do.
Nov. 11, 1912	60	10	Do.
Do.	60	10	Do.
Nov. 20, 1912	60	10	Do.
Feb. 8, 1913	58	10	Do.
Oct. 4, 1913	58	10	Do.
Feb. 8, 1913	57 to 58	15	Do.
Oct. 15, 1913	57	10	Do.
Do.	57	10	Do.
Oct. 4, 1913	56	10	<i>Nosema</i> infection produced.
Oct. 15, 1913	56	10	Do.
Jan. 8, 1913	55	20	Do.
Jan. 31, 1913	55	10	Do.

It will be observed from Table III that when *Nosema apis* was heated to 57° C. (134.6° F.) or higher for 10 minutes and fed to healthy bees no infection took place, but when held at temperatures below 57° C. (134.6° F.) for the same period of time the bees became *Nosema* infected. It is shown, therefore, that the minimum temperature that will destroy the germ *Nosema apis* in 10 minutes lies somewhere between 55° C. (131° F.) and 60° C. (140° F.), being quite near 57° C. (134.6° F.).

By way of parenthesis it might be well to say a word or two further regarding *Nosema* disease. The studies of this disease disclose the interesting fact that it is not a new one in American apiaries. There is no cause, therefore, for anticipating any additional losses to our apiaries. Indeed, since the presence of the disease is known, hopes may be entertained that methods will be determined for reducing the losses due to it. Considerable work must yet be done, however, before methods for its control can be recommended.

Nosema disease is being studied in England, Germany, Switzerland, and Australia. During the last two years the writer has devoted considerable time to its study in America. The plan is to continue the studies during the present year, after which it is hoped a further discussion of this disease will be justified.

SUMMARY AND GENERAL REMARKS.

The results of these experiments show that when they are maintained for 10 minutes the minimum temperatures that can be used for destroying the germs of the four bee diseases now known to be infectious are as follows:

(1) The minimum temperature for European foul brood lies somewhere between 60° C. (140° F.) and 65° C. (149° F.), being approximately 63° C. (145.4° F.).

(2) The minimum temperature for American foul brood lies somewhere between 90° C. (194° F.) and 100° C. (212° F.), being probably less than 98° C. (208.4° F.).

(3) The minimum temperature for sacbrood lies somewhere between 55° C. (131° F.) and 60° C. (140° F.), being approximately 58° C. (136.4° F.).

(4) The minimum temperature for Nosema disease lies between 55° C. (131° F.) and 60° C. (140° F.), being approximately 57° C. (134.6° F.).

It will be noted, therefore, that 63° C. (145.4° F.) for European foul brood, 98° C. (208.4° F.) for American foul brood, 58° C. (136.4° F.) for sacbrood, and 57° C. (134.6° F.) for Nosema disease are the approximate minimum temperatures at which the germs of these diseases, respectively, are destroyed. Since there are varying factors in experiments of this nature that tend to produce slight variations in results, these temperatures are referred to as being approximate. It is probable that future experiments may cause slight changes to be made in these conclusions. Nothing more than a comparatively slight variation is to be expected, however. In practice the beekeeper, in destroying these germs by heating, will naturally use a quantity of heat somewhat in excess of the minimum amount that is absolutely necessary.

Some generalizations may now be made which will be of interest to the beekeeper. The melting point of beeswax is between 62° C. (143.6° F.) and 64° C. (147.2° F.), inclusive. It will be observed that this same temperature in 10 minutes will destroy the germ causing European foul brood, and that it is about 10° F. above that which will destroy the germs of sacbrood and Nosema disease. A further interesting generalization may be made concerning the heating of honey. Honey when heated to 160° F. reaches a temperature 15° F. above the temperature necessary to destroy the germ of European foul brood and about 25° F. above the temperature that will destroy the infecting agents of sacbrood and Nosema disease. The infecting agents of these three diseases of the bee, therefore, will be destroyed when the temperature of 160° F. is used in the commercial handling of honey. Finally, it is believed that the results of this work on the thermal death point of the viruses of the bee diseases will be directly applicable to the control of these diseases.



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THE TEMPERATURE OF THE HONEYBEE CLUSTER IN WINTER.

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INTRODUCTION.

The care of bees in winter is one of the most perplexing problems confronting the beekeeper, especially in the North. This appears to be due chiefly to the fact that it is difficult to determine by direct observation the normal activities of the bee colony in winter, and consequently it is well-nigh impossible to determine what external conditions are most favorable except by the gross results of experience. Nor can we by a study of our wintering successes and failures determine definitely whether the same conditions of temperature and humidity are desirable throughout the entire winter. On account, therefore, of the lack of accurate knowledge of the activities of bees in the winter season this problem has been taken up with the aid of certain special apparatus and equipment. This preliminary report is not to be considered as giving definite recommendations as to the care of bees in winter, but rather is issued to make known to beekeepers some of the interesting results obtained in the first season's work on the behavior of the bees during the winter season.

American beekeepers lose thousands of dollars annually in winter from the actual death of colonies and even still more from those colonies that do not die, but which are reduced in numbers and vitality. The wintering problem is therefore a vitally important one. The factors influencing the welfare of the colony and the behavior of the bees are numerous and closely interrelated. Of the chief ones may be mentioned external temperature, food, ventilation, humidity, the condition of the colony at the beginning of winter, and various forms of irritation. In the present paper special emphasis is placed on heat production, by which is meant the responses of the bees of the cluster to the outer temperature and to changes in the outer temperature as manifested in the generation of heat by the bees.

NOTE.—This bulletin presents studies of bees as affected by temperature conditions during winter and is of special interest to beekeepers in the North.

A special reason for this emphasis in a preliminary paper is that all previous work on the temperature of the cluster in winter, of which there has been considerable, has failed to show definitely what the normal responses are. The data are often those of abnormal conditions and are therefore misleading, making them almost valueless for purposes of application. One source of error which is to be found in all the records known to the authors is the use of the mercury thermometer, for, when such a thermometer is used, it is almost impossible to avoid disturbing the cluster at each reading so that it reacts abnormally. Furthermore, as the authors will attempt to show at a later time, disturbances of the colony may influence the temperature of the cluster for a considerable period, often more than one day. Usually no account has been taken of the necessary corrections to be made for the mercury thermometer.

Because of the errors in other work on the subject, due to the use of mercury thermometers, the thermometers chosen for the work here recorded are of another kind. Electrical thermometers are used, by means of which readings can be made without approaching the hive, and the thermometers (couples) are of course permanently fastened in place. These are of the type known as thermocouples or thermal junctions and the readings are made by means of a potentiometer indicator and a sensitive galvanometer of the d'Arsonval type. The wires used in the thermocouples are copper and constantin (a copper-nickel alloy), giving an electromotive force of about 40 μ V per degree centigrade. A detailed description of the apparatus is impossible here, and it need only be stated that the method as used gives readings to an accuracy of 0.09° F. (0.05° C.); the thermometers are practically instantaneous in their action—that is, show changes in temperature without a “lag”; the readings of many thermometers can be made consecutively on one carefully calibrated instrument, insuring uniformity, which is impossible in using many mercury thermometers; and, a point of importance in such work, the readings can be made at the rate of two a minute, which would be impossible with widely scattered instruments. In all, 161,617 temperature readings were made during the winter 1912-13, and the work is being continued.

Part of the colonies are kept in a well-insulated room (used as a “bee cellar”) in the zoological laboratory of the University of Pennsylvania, Philadelphia, Pa., which can be kept at a temperature usually varying not over 2° F., far more uniform than the ordinary bee cellar. Abundant ventilation is provided, and the room is completely darkened to avoid possible disturbance by light. The temperatures of the indoor colonies are read from an adjoining laboratory to eliminate the possible errors due to disturbance, and the room is entered rarely (about once a week on an average and, if possible,

only after the day's records are made) and only when absolutely necessary. It is found that entering the constant-temperature room may under some conditions influence the behavior of the bees in a marked manner.

Other colonies are kept on the roof of the same laboratory, where they are left untouched from the beginning to the end of a series of readings. The wires of the thermometers are led to the room below through rubber tubes, and all the temperature readings are made at a distance, as is absolutely necessary to eliminate disturbance. Disturbances of outside colonies have also been found to influence their behavior in a pronounced manner, especially in cold weather.

By studying the temperature of various fixed points within each hive it has been found possible to use the temperature readings as a substitute for direct observations. After becoming familiar with the normal temperature and the temperatures incident to various activities one can tell the shape, location, and various activities of the cluster by a study of the temperature of different points within the hive and can, in fact, form an opinion as to the welfare of the colony. It has therefore been possible to follow closely the activities of each cluster without opening the hives and even without going near them.

THE INFLUENCE OF EXTERNAL TEMPERATURE ON HEAT PRODUCTION.

The colony (A) to be discussed under this heading was wintered out of doors (1912-13) on the roof, where the bees were free to fly whenever the weather permitted. It was in a 10-frame Langstroth hive, with the entrance reduced to $\frac{3}{8}$ inch deep and 8 inches wide, and was not packed or given additional protection. This hive contained 19 of the electrical thermometers—12 among the combs, 4 in the corners of the hive, and 3 on the bottom board. Readings were made hourly from 9 a. m. to 4 p. m. through the winter (Sept. 26 to Mar. 28), except Sundays and holidays, and at intervals additional readings were made every 15 minutes (or sometimes every 30 minutes) during the night (5 p. m. to 8.45 a. m.) for periods of several days each. In all, 41,413 temperature records were made for colony A.

The reaction of the cluster in heat production, as induced by changes in external temperature, is well shown by the records made from noon November 13 to 2 p. m., November 15 (1912), when readings were made hourly from 9 a. m. to 4 p. m. and every 15 minutes at night. From noon on November 13 the outside temperature dropped slowly until 6 a. m., November 15, and the weather was cloudy, so that the bees did not fly. It will be seen from the accompanying diagram (fig. 1) that at noon on the 13th the outside temperature was about 69.2° F. and all the points within the hive were



FIG. 1.—The outdoor temperature and temperature of the center of the cluster of bees in colony A from noon Nov. 13 to 2 p. m. Nov. 15, 1912. Outdoor temperatures are indicated by the heavy line. Short lines show temperatures of couples on the outer edge of the cluster at the time of first heat production.

then cooler than the outside air, due to the fact that it took some time for the inside of the hive to warm up. At 4 p. m. the outside temperature had dropped to 65.3° F., when it was lower than any of the points within the cluster, which had in the meantime become warmer. From this time until 6 p. m. the next day (14th) the temperature within the cluster gradually dropped as the outer air cooled, until the lowest one (No. 9) was 57° F. (Outside temperature, 48.2° F.) The generation of heat began at 6.15 p. m. at this point, which was to one side of the cluster, and is to be attributed to the movement of the bees in forming a definite cluster. At 6.30 p. m. a rise in temperature was noticed on thermometer 19, at the other side of the cluster. Until 10.15 p. m. the changes in temperature are probably to be interpreted as incidental to the formation of a compact cluster, and from this time until the next day at the close of the series of readings the thermometers within the cluster showed a considerably higher temperature than the outer air, or than the thermometers outside the cluster. The maximum in this series was reached at 3.15 a. m., November 15, when thermometer 12 in the center of the cluster registered over 89.4° F.

After the coldest outside temperature was reached and the outer air began to get warmer (6.15 a. m., November 15), there was a tendency for the cluster temperatures to drop. This is somewhat noticeable in the case now being discussed, and is more clearly seen in records obtained in other series. In general, after a period of cold, when the outside temperature begins to rise, the cluster temperatures drop slowly to meet the outside temperature. The generation of heat is reduced, or even discontinued, only to be increased when the outside temperature again drops, or when it gets high enough to induce greater activity, as in flight. It is found also by taking more frequent readings when the cluster temperature is above about 69° F. that it is less constant than when it is below this temperature, indicating that at temperatures above this point the bees move about to some extent, while between 57° and 69° they are quiet, unless flight is desirable owing to a long confinement.

This series of readings is supported by numerous records taken on this and other colonies throughout the winter and, since all the observations tend to confirm what was first seen on the record presented here, the authors feel justified in presenting a definite statement of the reactions of the cluster to outside temperatures. It may be added that a careful study of the records of previous investigators fails to show a similar statement on this subject. When a colony is without brood, if the bees do not fly and are not disturbed and if the temperature does not go too high, the bees generate practically no heat until the coolest point among the bees reaches a temperature of about 57° F. At temperatures above 57° F. a compact cluster is not formed, but the bees are widely distributed over the combs. At

the lower critical temperature, which is for the present stated as 57° F., the bees begin to form a compact cluster, and if the temperature of the air surrounding them continues to drop they begin to generate heat within the cluster, often reaching temperatures considerably higher than those at which they were formerly quiet and satisfied. It is evident, therefore, that the temperature within the cluster is far from being uniform in winter, as has been, in a sense, assumed among practical beekeepers. At the temperature at which other insects become less active (begin hibernation) the honeybee becomes more active and generates heat, in some cases until the temperature within the cluster is as high as that of the brood nest in summer. To sum up, when the temperature of a colony of undisturbed broodless bees is above 57° F. and below about 69° F. the bees are quiet and their temperature drifts with the outer temperature; at lower temperatures they form a compact cluster, and the temperature within it is raised by heat generated by the bees.

The authors desire to state that while the lower critical point, 57° F., appears rather well established, the observations up to the present do not justify too definite a statement concerning the upper limit of quiescence. It must be emphasized that these conditions do not apply when the colony has brood. The rearing of brood in winter causes a marked increase in heat production and constitutes a condition which may become one of the most disastrous that can befall a confined colony. This will be discussed at a later time.

When the heat production of the colony is explained, we are able to understand to some extent the divergence in the records obtained by other observers. It has, of course, long been known that bees generate heat, and it has been pointed out that during cold weather the temperature of the cluster is often higher than during warmer weather. While the temperatures previously recorded are in most cases abnormal, due to disturbance, the chief difficulty in understanding the phenomena which take place is due to insufficient observations. For example, if between noon November 13 and 2 p. m. November 15 only a half dozen temperature records had been made for the cluster (and perhaps without finding the warmest part of it) and the outside air, it would have been impossible to determine the limits of heat production. Most observers have been satisfied with a few observations, and seemingly everyone who has inserted a thermometer in a hive has felt called upon to publish the results, thereby only confusing the problem.

THE EFFECT OF CONFINEMENT AND THE ACCUMULATION OF FECES.

Before beginning a discussion of the effect of confinement and the accumulation of feces, it may be recalled that during the active summer season the length of life of worker bees is in a sense deter-

mined by the work done by them, rather than by days or weeks. The greater the necessity for excessive activity the shorter the term of life. The authors believe that they have evidence to prove that this applies to the winter also, and this belief is entirely supported by the experience of beekeepers everywhere. That bees may come out of winter quarters strong in numbers and vitality it follows that the work to be done by the bees in the winter should be reduced to a minimum; and the winter problem, as thus interpreted, is therefore to find the conditions under which broodless bees do the least work. The work which broodless bees do in winter consists, so far as has been determined, solely in the production of heat or in activity incident to flying on warm days (if free to fly), and therefore the problem, so far as it is under the control of the beekeeper, is primarily to obviate the necessity for the production of heat. If brood is reared the work of the bees is necessarily enormously increased, and their vitality is correspondingly decreased. So far as evidence is available in this work, the colony is not fully recompensed for this expenditure of energy by an increase in the strength of the colony by bees thus reared.

The colonies¹ to be discussed under this heading (Nos. 1 and 3) were wintered in the constant-temperature room in special 6-frame hives (to economize space and concentrate the colony so that fewer thermometers would be required) with full entrances and were not propolized or sealed at the top. During the regular series of readings the room was kept at a temperature which rarely dropped below 40° F. or went above 45° F., and the average temperature from October 14 to March 6 was 42.67° F. This temperature was chosen as being nearly the one usually considered best by beekeepers. The foods given these colonies were stored in the combs, just as placed by the bees. There was some pollen available in colony No. 1. (Fig. 2.)

According to what has been said in the previous section, we should expect bees at such a temperature to maintain a compact cluster and to generate some heat at all times. This was actually the case, the temperature of the interior of the clusters dropping below 64° F. only a few times in either colony.

Colony No. 1, on honey stores, was in the constant-temperature room from October 12, 1912, to March 24, 1913, or 163 days.² It

¹ In order that the young bees might all get a flight before the winter confinement, the two colonies here discussed were placed in the constant-temperature room after the brood had been removed. They were kept here several days, removed for a flight, and then returned to the room for the regular series. The significance of this manipulation must be reserved for a later discussion. This explanation is made to show how it was possible to put these colonies in the room so early in a climate as mild as that at Philadelphia. The object was, of course, to increase the time available for observation. Bees are usually not wintered in cellars in climates as mild as that of Philadelphia.

² In all, 24,077 temperature records were made for this colony.

was then removed for a flight and put back the same evening, where it remained until March 28. From March 7 at 9 a. m. until March 28 at 4 p. m. readings were made on this colony every 15 minutes night and day, with the exception of the period between 9 a. m. and 7 p. m. on the 24th, when it was out of doors. During this period of three weeks the temperature of the room was changed slowly, being raised as high as 64° F. and cooled to 13° F.

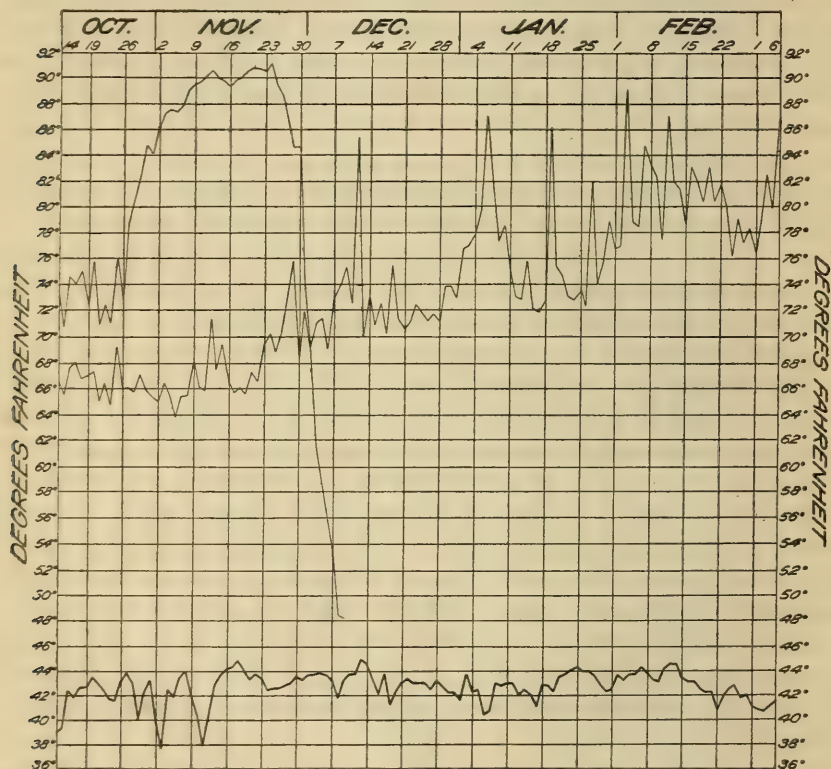


FIG. 2.—Average daily temperatures of the center of the cluster of bees in colonies 1 and 3 and room temperatures, Oct. 14, 1912, to Mar. 6, 1913. Taken from readings made hourly from 9 a. m. to 4 p. m. The room temperatures are indicated by the heavy line.

When this colony was first placed in the room for the regular series of readings, after a preliminary confinement, October 12 (the readings were begun Monday, Oct. 14), it maintained a cluster temperature which usually lay between 64° and 68° F., the daily average temperature departing from these rather narrow limits only four times up to November 22. The average temperature is 66.5° F. During the first five weeks the temperature of the room was less regular than later (due to faulty working of the regulating apparatus), and this doubtless accounts for some irregularities in the cluster temperature. At first the three thermometers in the cluster (1, 2, and 5) gave tem-

perature readings quite close together, while thermometer 6, which was near the cluster, gave readings intermediate between the three thermometers of the cluster and the four others in the hive, farther from the cluster. After November 22 the records of the thermometers in the cluster were more widely separated and the temperature of the center of the cluster (shown on thermometer 5) tended to rise gradually. It varied constantly, but by December 7 and from then until the end of the month, it averaged between 69° and 75° F. On November 29 and December 12 the cluster temperature rose to over 88° F. From the 1st of January until March 6, which ended the regular series of readings, the cluster temperature became more and more irregular, and on January 20 the cluster moved (probably to accommodate itself to the stores) until thermometer 2 was nearer the center and showed a higher temperature than thermometer 5. The size of the cluster was gradually decreased by the death of bees, and all the thermometers except 2 and 6 show a gradual decrease in temperature until finally, from about February 25 to March 6, they are all low and of nearly equal temperature. The two thermometers giving high readings continued to show in general a higher and higher average temperature and to become more irregular (except from February 15 to March 1), the periods of increased heat becoming more frequent. There was absolutely no regularity in these intervals. After February 1 the temperature of the cluster varied between 75° and 91° F., the average from February 1 being 85.4° F.

On March 6 all colonies in the constant-temperature room except two were removed. The colony described above (No. 1) and one other (No. 12), not to be described at present, were left. On March 7 at 9 a. m. the temperature of the room stood at 42° F., and the temperature of the interior of the cluster was about 84° F. The brine which cooled the room was then shut off and the temperature of the room rose very slowly and regularly, until on March 11 at 8.45 a. m. it was 64° F. For the first day the temperature of the cluster was slightly variable, and at 10.45 p. m. thermometer 6, which had been cooler than thermometer 2, showed a rise in temperature (probably due to a shifting of the cluster), and from then on to the 24th they were nearly of the same temperature at all times. On March 8, at 3 a. m., thermometer 2 rose to 87° F. (room temperature, 48.5° F.), having previously shown a cooling. The cluster temperature then dropped slightly, showing relatively little variation until at 4.15 p. m., March 9, it stood at 77.3° F. (room temperature, 55.7° F.). As the room temperature continued to rise, the cluster temperature increased still more rapidly, until at 8.15 a. m., March 11, it reached 93° F. (room temperature, 64.2° F.). A little brine was now turned on, sufficient to lower the temperature gradually to 58° F. at 9 a. m., March 12, and it again rose to 63.3° F. at 5.45 p. m.,

March 15. During this period the cluster temperature followed the room temperature, but remained constantly over 20° warmer. The room was again cooled slowly, and the cluster temperature dropped until on March 16, at 3 p. m., the room was 49° F. and the cluster 77.5° F. As the room continued to cool, the cluster temperature increased, the bees responding to the colder temperature, until at 4.15 a. m., March 17, the room was 48° F. and the cluster 88° F. The room then gradually warmed, and again the temperature of the cluster dropped and then again rose with the room temperature, remaining always over 20° warmer. At 6.45 p. m., March 19, the brine was turned on full and the room cooled rapidly, reaching the minimum of 13° F. at 9 p. m., March 20. At no time, however, did any of the thermometers in the hive record a temperature below 33° F. Here it remained constant within 0.1° F. for about six hours, during which time the cluster temperature varied between 86.5° and 89.5° F. (a difference between the room and the cluster temperatures of 73° to 76° F.). The brine was now shut off and the room again warmed until 9 a. m., March 24, when it reached a temperature of 44.5° F. During this warming the cluster cooled until at the close it was varying between 72° and 79° F.

As stated above, the colony was now (9 a. m., March 24) removed for a flight and put back the same day at 7 p. m. In the meantime the room was cooled to 33° F. When the bees were put back into the room the temperature of the entire inside of the hive showed great variation and naturally an increase due to the warming up while out of doors and to the activities of a good flight. The points outside the cluster dropped rapidly, but it was midnight, March 25 (31 hours), before the curves of temperature again appeared normal. The room was slowly warmed to 63.2° F. at 6.30 p. m., March 26, and then slightly cooled to 54° F. at 6 a. m., March 27, and again warmed to 58.5° F. at the close of the series, 4 p. m., March 28. After the flight the temperature of the cluster never dropped below 89.5° F., and the highest temperature reached was over 95° F. (soon after the flight). Thermometer 6 remained high, but thermometer 2, which had previously been high, now approached the other thermometers, probably due to a rapid loss of bees and to a decrease in the number of bees during the flight. It must be recalled that these bees had been confined for an abnormally long time and were subjected to treatment which is at least unusual. After this colony was taken from the room for the last time it was found that thermometer 6 was over a patch of larvæ, and, estimating as accurately as possible, the eggs from which these hatched must have been laid at the time when the room was coldest (March 20–21) and when the cluster temperature was at its highest point. There had been no brood previously, according to the temperature records as compared with those

of this colony earlier and with those of other colonies, nor was there much evidence of increased heat production due to the presence of brood until after the flight. Probably no extra heat was produced for the eggs, and possibly the hatching of the eggs was somewhat delayed by the low outer temperature. The effects on the cluster temperature which might be expected from a flight, in relieving the accumulation of feces, were not observed, because brood rearing had been begun.

Colony No. 3 was placed in the constant-temperature room October 12, 1912, after a good flight, and readings were begun on Monday, the 14th. In all, 2,165 temperature records were made on Colony 3. The stores provided this colony consisted of honeydew honey, which was gathered in the department apiary and which, since it granulated almost at once, had been removed by melting up the combs which contained it. After this operation it remained liquid. During the summer of 1912 some of this honeydew honey was fed to a colony in the open, during a dearth of nectar, and was stored in new combs above the brood chamber, in which no cells of pollen were to be found. After the second storing the honeydew honey was clear, well ripened, and did not granulate. This colony was also in a 6-frame hive, as previously described, and contained five thermometers (Nos. 14-18) among the combs. It is of course well known to beekeepers that honeydew honey is not a good food for winter.

When this colony was first put into the constant-temperature room it behaved much as did Colony No. 1, except that the temperature varied between 69° and 78.7° F. for the first week, being slightly higher and more variable than that of Colony No. 1. The second week it remained much the same, the temperature, however, varying between 69° and 80° F. From this time on the temperature of the center of the cluster rose rapidly, never dropping below 79° F. from October 29 almost to the close of the readings. After November 4 the temperature remained above 86° F., and after November 11 it dropped below 89° F. only twice until the end. Thermometer 17 at first read about 4° below thermometer 14, but after November 11 they were close together until November 25, when thermometer 17 began to cool rapidly, due to loss of bees, and after November 30 thermometer 14 cooled rapidly until, on December 9, it showed that no more bees remained alive. From December 2 to 7, inclusive, there was little heat generated, due to the scarcity of bees. It is of interest to observe the records of thermometer 16, near the cluster, but usually outside of it. It at first showed a temperature but little higher than the two thermometers away from the cluster, but on October 31 it began to rise until, on November 12, it reached 80.5° F., when it was doubtless covered by the bees. Even the two thermometers (15 and 18) clear to the back of the hive rose until, on November 13, they

recorded 61.5° F. These thermometers showed about the same temperatures for about 10 days, and then these two and thermometer 16 showed a cooling, since the bees were dying so fast that there were no longer enough to warm up these thermometers away from the center of activity. It was to be expected that this colony would die, and the experiment was performed to learn the phenomena incident to the loss.

Before summing up the results of these two colonies, Nos. 1 and 3, it may be stated that, so far as the evidence here presented is concerned, the results as far as here discussed are confirmed by records from 10 other colonies kept in the constant-temperature room, but fed other foods and otherwise different. There is in all of the records no evidence which the authors can interpret as at all contrary to the views here stated. A discussion of these other colonies is reserved.

It is evident from the behavior of colony No. 1 that at least one factor entered which gradually caused the bees in the cluster to generate more and more heat until at the beginning of the special series, March 7, the cluster temperature was about 20° warmer than it was at the same room temperature at the beginning of the confinement. It is also seen that during the special series, March 7-24, the cluster temperature always remained at least 20° above the room temperature, whereas from the discussion of bees unconfined (Colony A) we might expect them to cease heat generation when above the lower critical temperature (57° F.). In the case of colony 3, fed on honeydew honey stores, the factor which caused more heat to be produced evidently increased much more rapidly. As stated previously, honeydew honey is a poor food for winter and is so recognized. It contains the same sugars as honey, but contains in addition a considerable amount of dextrin, the particular lot fed to colony 3 containing 4.55 per cent while good honeys contain only a fraction of 1 per cent. From the evidence at hand it appears that dextrin can not be digested by bees and, whether or not this is the explanation, honeydew honey causes a rapid accumulation of feces which usually results in the condition known as dysentery, in bad cases of which the feces are voided in the hive. In the case of colony 3 the whole hive inside and out, as well as the frames and combs, were spotted badly, the inside of the hive being practically covered. Even with fine honey stores such a spotting is usually noticed after a prolonged confinement, especially in severe weather (or during brood rearing). It therefore appears that the accumulation of feces acts as an irritant, causing the bees to become more active and consequently (see later section) to maintain a higher temperature. We are therefore justified in believing that the cause of poor wintering on honeydew honey is due to excessive activity, resulting in the bees wearing themselves out and ultimately in the death of the colony.

In the case of colonies on good stores (e. g., colony 1) the feces accumulate more slowly and the excess activity is not so marked and is induced more gradually. The accumulation of feces due to confinement causes increased activity and this in turn is the cause of excessive heat production, resulting in a reduction in the vitality of the bees.

It therefore follows that excessive activity causes the consumption of more food, resulting in turn in more feces, so that colonies on poor stores are traveling in a vicious circle, which, if the feces can not be discharged, results in the death of the colony. In the work here recorded no attention was paid to the theory that dysentery is due to an infection, since there is nothing in the observations made that lends any support to that idea. If there is more than one kind of dysentery, as has been held, then the observations here recorded must be considered as applying only to the type which can be induced at will in any confined colony by giving poor food and which, as has been long recognized, can be relieved at once by an opportunity for flight.

While the activity of the cluster is greater at some times than at others, there are not, as has been held, regular intervals of activity at which the colony rouses itself to take food. At no time is a colony kept at a room temperature of 45° F. or less in a condition which can be characterized as inactive. Presumably the reported "intervals of activity" have occurred when the colony made a noise due to disturbance by the beekeeper.

The bees in colony 3 were compelled to work constantly to maintain so high a cluster temperature. In fact, they did more work than colonies wintered in the open air. Keeping these bees in a cellar protected them from low outside temperatures, but the lack of opportunity for a normal ejection of feces caused a condition more serious than extreme cold weather. We seem to have here an explanation of the fact, often observed by beekeepers, that some colonies wintered in the cellar are in worse condition in the spring than colonies that are exposed to severe cold. Poor food is evidently a more serious handicap than low temperature.

METHODS OF HEAT PRODUCTION AND CONSERVATION.

A colony of bees in cold weather forms a compact, approximately spherical cluster, but this cluster is not, as is usually believed, uniformly compact. In order to study the formation of the cluster and as an aid to interpreting the temperature records in terms of action, a colony (C) was placed out of doors in a narrow hive with double-glass sides and top, and the stores were so arranged that the only space available for the formation of the cluster was next to the glass on one side, where it could be kept under direct observation. Since

the bees did not have room for a spherical cluster, they formed a ring on the glass. Thermometers were then placed close together in the outside space, so that the temperatures of various points could be determined as desired. This hive was on the roof, and, while one person watched the bees, constant communication could be kept up with the person reading the temperatures in the room below by means of a telephone, arranged so that the hands of both observers were free. This colony was of course in the light, but the normal cluster was nevertheless observed. It was disturbed as little as possible.

The nearly spherical cluster of bees consists, between the combs and sometimes above or below them, of an outer shell of bees close together with their heads toward the center. This ring may be several layers thick. The position with the heads inward is typical, except when condensed moisture drops on the cluster as it often does in cool weather, when the bees at the top turn so that their heads are upward. The bees in this outer shell are quiet except for an occasional shifting of position. Inside this rather definite shell the bees between the combs are not so close together nor are they headed in any one way. Considerable movement, such as walking, moving the abdomen from side to side, and rapid fanning of the wings, takes place inside the sphere and when a bee becomes unusually active the adjoining bees move away, leaving an open space in which it can move freely. Two bees may often be seen tugging at each other. In addition to the bees between the combs, placed as above described, others are in the empty cells of the comb on which the cluster is always formed, always with their heads in. A verification of these statements is contained in the following observations, and the experiment may easily be repeated by anyone. For the purpose of obtaining a colony without combs for another experiment, a hive was opened December 15, 1913, while the outside temperature was low enough to cause the formation of a compact cluster. When the combs were separated the circle of bees in the shell was clearly observed. When a comb from the center of the cluster was shaken the active bees in the center of the circle dropped off readily, and those in the outer shell which were somewhat sluggish were removed with more difficulty. After this was done those occupying empty cells in the center of the sphere backed out of the cells and were shaken off. Finally those occupying cells in the border of the sphere backed out, showing a well-marked circle on the combs. Evidently the bees in the shell, whether in the cells or between the combs, are less active than those in the interior of the cluster. Naturally such a manipulation as this is not to be recommended, except for purposes of demonstration.

It is clear from observations previously recorded that the highest temperatures are those of points in the center of this shell, and this is

to be expected, as the heat is generated here. The outer shell constitutes an ideal insulator for the conservation of the heat, since the bees arranged so close together form small dead air spaces in their interlacing hairs, especially those of the thorax, and afford still more insulation with their bodies. The abdomens of the bees in the outer row are practically separate one from another, and must often be exposed to severe cold. That this method of conserving heat is effective is shown by observations on undisturbed colonies out of doors. For example, on January 14, 1914, there was at 9 a. m. a difference of 68° F. between thermometers 14 (center of the sphere) and 16 (outside the cluster) of Colony D, which were less than $4\frac{1}{2}$ inches apart on the same level in the same space between combs, and a difference of 75° F. between this couple and the bottom board $4\frac{1}{4}$ inches below it. What this difference might sometimes be in colder climates may be imagined. Examples of this kind might be multiplied indefinitely from the records of these experiments.

The source of the heat of the cluster must, of course, be the oxidation of the food consumed by the bees. The bee is classed as a cold-blooded animal in that the temperature of the individual bee is practically that of the surrounding medium. There is obviously, from the records just given, no internal regulation of the temperature of the body such as is found in birds and mammals, for the temperature of a broodless cluster varies greatly. From the observations made on the various colonies, especially Colony C, it is clear that heat for the warming of the cluster is produced by muscular activity. While, of course, some heat is doubtless liberated by other life processes, this is practically negligible when bees are quiet, as in Colony A when above 57° F. That higher temperatures may be produced, greatly increased muscular activity is required, and in Colony C in cold weather bees in the center of the shell of insulating bees were seen fanning vigorously and executing other movements, such as shaking and rapid respiration. We thus have the paradoxical condition that bees fan to heat the cluster in winter as well as to cool the hive in summer. Observations of this kind were repeated beyond number, and this theory of the method of heat production is entirely supported by the repeated observation of a humming noise from the cluster during cold weather.

A few details of the observations on Colony C may be of interest. For example, one bee was observed fanning vigorously for $7\frac{1}{2}$ minutes (9.53 to 10.00 $\frac{1}{2}$ a. m., Jan. 23) while the other bees kept a space cleared for it. The temperature of the nearest thermometer rose $\frac{1}{2}^{\circ}$ F. during this time. At 9.52 this thermometer was almost a degree cooler than at the time of greatest heat during the fanning. The rapidity of fanning of the wings varied, and toward the end of the time it became so slow that the outline of the wings was distinguishable. After the

excessive activity this bee stood in the same place for a time. Rapid respiration may play a more important part in heat production than at first appears. One bee was observed to breathe 21 times in 14 seconds and then cease the rapid respiration. On other occasions 50 or more bees would begin shaking their bodies from side to side.

It has been shown in earlier sections that feces in the rectum cause irritation, which induces increased activity and causes greater heat production. It has also been found that other kinds of irritation bring about the same result, but a discussion of these points can not be undertaken here. It is at least evident from the records obtained in this work that colonies of bees in winter, either in cellars or out of doors, should be disturbed as little as possible. This appears to apply especially to cold weather out of doors or in the cellar, especially after the colony has been confined for some time.

The facts mentioned concerning the ability of the bees to conserve the heat generated will perhaps raise the question as to the temperature of the hive outside the cluster in cold weather, when the cluster is compact. In the case of Colony A the temperature of the hive outside the cluster was often practically as low as the outside temperature. This colony was not packed and had a rather large entrance. If the cluster forms such an efficient insulator in itself it might be presumed that packing about the hive is of little value and that it might even be harmful, in that it would not serve to conserve heat and would prevent the heat from the sun from penetrating to the cluster. This line of reasoning, however, does not follow, and in any case it is unsafe to speculate about these things without more facts. The effects of various forms of packing are being studied.

In closing it may be desirable again to state that too hasty conclusions must not be drawn from the facts here presented. For example, the records on heat production might be interpreted as indicating the desirability of a cellar temperature higher than beekeepers usually believe to be best. Experiments to test such a theory are now being carried on, and it is found that a broad statement as to the best cellar temperature can not yet be given. Under most conditions colonies can not be brought to the critical temperature, 57° F., without disturbance. It is hoped that more work will throw some much-needed light on this important subject.

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DOMESTIC BREEDS OF SHEEP IN AMERICA.

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INTRODUCTION.

All the domestic sheep in America have originated from importations, most of which have been made from European countries since the beginning of the nineteenth century. These breeds have not yet been able to find themselves fully, and there are not the clearly defined areas devoted to certain classes such as are common in England; still there is a gradual tendency toward segregation.

The fine wools are grazing upon the western ranges and to a lesser extent through the Ohio fine-wool region. They are undergoing some changes to improve the carcass and increase the length of wool; some foreign blood is being used to do it; nevertheless these sections may still be regarded as being fine wool in character.

In Tennessee, Virginia, and Kentucky, the spring-lamb region of America, the Southdown lambs are very popular. To a lesser extent some of the other mutton breeds are gradually gaining precedence.

Through the central farming section of the country the medium-wool breeds have taken possession, the long wools largely yielding for a location more favorable to them in the North and Northwest, notably Canada, Utah, Idaho, Montana, and Oregon.

It is not always possible to say that there is one best breed for any section. There may be two or three that would do equally as well, but it is undeniable that some breeds are far more suitable than others for a given location. All the breeds have their good qualities and most of them, if properly handled, will give good results in some section of America. The problem is to get the ones best adapted to particular conditions. Some breeds have a larger number of high-class individuals than others, but a truly successful breeder can improve any of them.

NOTE.—This bulletin gives detailed information as to the origin, adaptability, distribution, distinguishing characteristics, etc., of the various domestic breeds of sheep. It is of especial interest to sheep breeders and to the sheep grower who is desirous of securing the best breed adapted to his particular locality.

As a rule, but one breed should be selected. Where there is more than one breed upon a farm it is a difficult matter to keep the gates all closed at the proper time and prevent crossing. If several farms are available more breeds can be handled, but the difficulties in management are much increased. The most successful sheep breeders in America handle but one breed. The fact that there are more breeds than in any other class of farm animals may in itself make the selection of one breed rather difficult. Some of the deciding factors should be climatic conditions, feeds available, elevations, what particular line of the industry is to be followed, and popularity of the breed.

The effect of climate is strikingly illustrated in the evolution of the sheep industry of the extreme Northwest. The Willamette Valley in Oregon, now so famous for its long wools, was once partly occupied by fine-wool sheep. The large amount of rainfall, which comes in a long-continued drizzle, caused the hay and weed seeds that became lodged in the wool to grow and become green upon the sheep's back. The Merino breeds were decidedly out of place there. After a time the Lincoln and other long-wool breeds were introduced and the industry assumed a different aspect. Their long locks act as a thatch, carrying the water off, and these breeds thrive as they do in few other places except their native counties in England.

The kind of feed produced is of importance. The larger breeds have developed upon land that has produced abundantly. They are capable of taking care of a larger amount of feed, such as the moist fertile lowlands produce, while the smaller breeds succeed better upon the less abundant fare of drier and less fertile pastures. There is evidently some connection between the general higher quality of the smaller breeds and the scanty, more nutritious feeds that they receive under natural conditions. If they are removed to the lowland they lose much of their characteristic type and quality.

The effect of elevation upon a breed is also apparent, but how much of this effect is due to the amounts and kinds of feed it is difficult to determine. Certain it is that the mountain breeds are smaller, more active, more hardy, and better able to care for themselves than their down or lowland neighbors.

The importance of hardiness in the mountain breeds was shown during the last century along the Scottish border. The Cheviot had for a number of years been displacing the Black-faced Highland breed because of its finer quality of wool and somewhat better carcass. A number of severe winters worked havoc among the flocks of the former breed by causing a very heavy lamb loss, and the Highland breed, because of its hardiness, came back into its own.

The effect of the soil upon sheep is somewhat obscured in the effects of feed, elevation, etc. That there is some effect can not be denied, but the extent of this is an unsolved problem.

Whether the breeder expects to specialize upon some particular line of sheep farming should likewise be instrumental in making a decision. If winter lambs are to be produced a breed must be secured that will breed at the right season of the year, and not all will do this. The Dorset, Merino, and Tunis have given the best satisfaction thus far.

The popularity of a breed will often have its effect in influencing one's decision. Some breeds have been developed under conditions that are more general, or else they have a wider range of adaptability than others. The popularity of several breeds in this country is due to this fact. No better illustrations of these can be mentioned than the Merinos and Shropshires that are found from Maine to California. Some of the minor breeds need men who will place them before the public, as there can be no doubt as to the effect of a wide-awake breed association in advancing a breed.

It is well before making a selection to consider carefully the most popular breed in your community. There is usually some good reason for it being popular, but occasionally because of fashion a breed will enjoy a "boom" that it does not rightly deserve. In some States at the present time there are colonies of breeders handling certain breeds, and buyers are attracted there because there are excellent opportunities for selection in the neighborhood. There are also advantages connected with buying stock near home. The keen competition offered by some of the classes in the show ring has been a lure that has caused some men to take up a certain breed. Others have been content to win more often in the smaller classes where the winnings are easier.

Some breeds are regarded as needing more care than others; at any rate they become more unsightly if denied this attention. However, no flock will thrive upon mismanagement. Good appearance is always desirable, and sometimes it is of prime importance. The use of sheep for keeping the lawns of parks and country places in trim has been in effect in this country for years and here attractiveness is indispensable. The Southdown has proven very popular for this purpose.

The cost of foundation stock will undoubtedly have considerable influence with some people in making a selection. However, too much importance should not be attached to this. Often breeding stock of some breed unadapted to your locality can be bought very reasonably, but if the flock was established there would be little demand for its products and the venture would be likely to meet with failure.

The characteristics of the breeds as regards the color of the face and legs and whether or not they are horned have been regarded as of considerable weight, but it is doubtful whether these are as important as is sometimes inferred.

It is the purpose of this bulletin to point out the main characteristics of each breed. Some of the early history given may therefore seem irrelevant, but it is of importance. The age of a breed is largely indicative of the degree of fixity of type. A knowledge of the foundation stock is important, as it reveals latent characters that might crop out and that should be guarded against by the breeder, and so on. While it is the object to point out the importance of selection, it is not intended to minimize the necessity for proper care and management. Too many purebred flocks of high character have been established in this country only to go to ruin on account of poor care. This side of flock husbandry has been treated in Bulletin No. 20 of the Agricultural Department series.

CLASSIFICATION OF THE BREEDS.

There are probably nearly as many classifications of the breeds of sheep as there are breeds. Almost every prominent author of literature in the ovine world has expressed views upon the subject. They have approached the task from almost every possible angle; consequently we have classifications based upon the color of the face, including the light and dark faced sheep, upon the presence or absence of horns, and upon the topographical origin of the breed, such as the mountain, upland, and lowland breeds. There are other classifications based upon the geographical origin of the breeds; for instance, the British, Island, and foreign breeds; upon anatomical structure, the fat tails and the broad tails, and so on. It is hardly necessary to say that any classification must be more or less arbitrary, as the different divisions grade almost imperceptibly into one another.

The most important classifications are those based upon the wool, of which there are several. Some of these are based upon the length, but as this property is more dependent upon the circumstances under which the sheep are kept than is the degree of fineness, we will base our classification upon the latter quality.

FINE WOOLS.

American A, B, and C type Merinos.

Rambouilleta.

MEDIUM WOOLS.

Southdown.

Suffolk.

Lonk.

Shropshire.

Cheviot.

Ryeland.

Hampshire.

Welsh Mountain.

Kerry Hill.

Oxford.

Tunis.

Dorset Horn.

Exmoor Horn.

COARSE WOOL.

Leicester.

Romney Marsh.

Black faced Highland.

Cotswold.

Wensleydale.

Karakule.

Lincoln.

Dartmoor.

Persian.

WOOLLESS.

Barbados.

Barbary.

Deciding the order in which to take up the breeds of the different classes is not so easy as it seems upon first thought. The importance

- 1 CORNWALL
- 2 DEVON
- 3 SOMERSET
- 4 DORSET
- 5 WILTS
- 6 HAMPSHIRE
- 7 SURREY
- 8 WEST SUSSEX
- 9 EAST SUSSEX
- 10 KENT
- 11 LONDON
- 12 ESSEX
- 13 MIDDLESEX
- 14 HERTS
- 15 BUCKS
- 16 BERKS
- 17 OXFORD
- 18 GLOUCESTER
- 19 MONMOUTH
- 20 HEREFORD
- 21 WORCESTER
- 22 WARWICK
- 23 NORTHAMPTON
- 24 BEDFORD
- 25 HUNTS
- 26 CAMBS.
- 27 SUFFOLK
- 28 NORFOLK
- 29 I. OF ELY
- 30 PETERBOROUGH
- 31 RUTLAND
- 32 HOLLAND
- 33 KESTEVEN
- 34 NOTTS
- 35 LINCOLN
- 36 LEICESTER
- 37 DERBY
- 38 STAFFORD
- 39 SALOP
- 40 CHESTER
- 41 LANCASTER
- 42 YORK
- 43 DURHAM
- 44 WESTMORELAND
- 45 CUMBERLAND
- 46 NORTHUMBRIA
- 47 BERWICK
- 48 ROXBURGH
- 49 SELKIRK
- 50 PEEBLES
- 51 DUMFRIES
- 52 KIRKCUDBRIGHT
- 53 WIGTOWN
- 54 AYR
- 55 LANARK
- 56 MIDLOTHIAN
- 57 HADDINGTON
- 58 LINLITHGOW
- 59 RENFREW
- 60 DUMFRIES
- 61 STIRLING
- 62 FIFE
- 63 KINROSS
- 64 CLACK
- 65 PERTH
- 66 FORFAR
- 67 KINCARDINE
- 68 ABERDEEN
- 69 BANFF
- 70 ELGIN
- 71 NAIRN
- 72 ARGYLE
- 73 INVERNESS
- 74 ROSS
- 75 CROMARTY
- 76 SUTHERLAND
- 77 CAITHNESS
- 78 GLAMORGAN
- 79 BRECON
- 80 CAERMARTHEN
- 81 PEMBROKE
- 82 CARDIGAN
- 83 RADNOR
- 84 MONTGOMERY
- 85 MERIONETH
- 86 DENBIGH
- 87 FLINT
- 88 CAERNARVON



FIG. 1.—Map showing place of origin of the breeds of sheep of Great Britain that have been imported into the United States.

of the breed is indicated, but not necessarily decided, by the number of purebred animals recorded. The records usually extend over a number of years and few of the sheep that have died have been noted

in the records. Hence it is difficult to tell the actual number of living animals.

Many breeds have enjoyed periods of unusual prosperity, or "booms," as they are commonly called. In some cases these have been more or less permanent; in others, only temporary occurrences. Thus it is possible that a breed might have a large number of animals recorded and yet not be so important as one having many less because it has passed the zenith of its popularity.

But even though we could obtain the actual number of living sheep recorded in each of the breed associations, taking them up in the order of their numerical importance would not be satisfactory because a breed is sometimes important in grading up the common flocks, while the number of its purebred sheep remains comparatively small.

Notwithstanding the fact that sheep farming for wool alone is unprofitable, the Merino, distinctly a wool breed, is the foundation of American sheep husbandry. By far the greater number of grade flocks of America, especially through one section centering in Ohio, and another comprising the bulk of territory west of the Mississippi River, are of fine-wool origin. For this reason it is fitting that the Merinos be treated first.

In the medium-wool types the Southdown is well down the list in numbers recorded, yet the important part this breed has played in the evolution and development of the other "down" breeds warrants it first place in this division. When there is no other preference between breeds, they are placed according to their numerical strength, care being taken to give the minor breeds a subordinate position.

Among the long wools we have a case similar to that of the Southdown. The Leicester is relatively unimportant in the United States as compared to the other long-wool breeds, notably the Cotswold and Lincoln. Yet the Leicester entered the foundation stock of the long wools, and therefore it should be placed first in the long-wool class.

The unimportant woolless sheep are dealt with last.

THE MERINO.

The Spanish Merino is the progenitor of all the various Merino breeds, classes, and types. Fine-wool sheep, presumably the ancestors of the present breeds, were well established in Spain at the dawn of the Christian era, and as early as the eighth century extensive textile arts were carried on by the Saracens at Seville and the wool was furnished by the flocks of the surrounding country.

There were two great groups of Spanish Merinos, known as the Estantes, or Stationary, and the Transhumantes, or Migratory. The latter group was considered much superior. These groups were further divided into a number of more or less important families. Little improvement took place in this breed in Spain, especially with regards

to mutton qualities, which were very inferior, but the wool of these sheep has been noted for its fineness for centuries.

Merinos were introduced into Sweden about 1723; Saxony, 1765; Silesia, 1768; France, 1783; United States, 1793; Cape of Good Hope, 1797, and shortly afterwards into Australia. In all these countries distinct types or breeds have arisen, and marked improvements have taken place in many instances. In France the size, mutton qualities, and amount of fleece have been increased; in Saxony the fiber is of finer quality than that of the Spanish Merino; and similar improvements have taken place in other foreign lands. The improvements that have taken place in the United States will be discussed in a later paragraph.

The world-wide distribution of the Merino can be accounted for by some of its peculiar qualities. The most important of these are its wide range of adaptability, its marked degree of hardiness (contrary to its apparently weak conformation), its inherent characteristic of producing a heavy fleece of superior quality, and its habit of grazing, these sheep banding together in large herds while feeding.

The history of the Merino in this country has been marked by alternating periods of popularity. The first importation was brought over by Mr. William Foster, of Boston, Mass., in 1793. The shipment consisted of one ram and two ewes, and they were presented to Mr. Andrew Craigue, of Cambridge. The latter gentleman failed to realize their value, and he had them slaughtered for mutton purposes. Later, when he paid \$1,000 for a single ram, he recognized his mistake. In 1801 other small importations came over, and the Merinos gradually increased in popularity and numbers until 1810, when the fine-wool craze started and they were literally imported by the thousands. In that year alone it is said that 10,000 were brought over. Ewes sold for as much as \$1,000 and rams for \$1,500. After the war of 1812 the boom died down, and sheep that formerly sold for hundreds of dollars could now be purchased for \$1 a head. Spanish Merinos have not been imported into this country since that period, though Saxon and French Merinos were subsequently introduced.

Half a century elapsed before the Merino was again in its glory. The second craze swept over the country during the early sixties. At this time rams were frequently valued as highly as \$2,500, and an offer of \$10,000 for one ram was reported.

The American type known as the Vermont Merino was developed mainly in New England. It became the heaviest wool-producing sheep in the world and the fiber was of exceptional strength and fineness. These sheep are distinctive in having heavy folds over the body, with the exception of on the back, these folds giving a larger surface for the production of wool. The wool extends over the head in a compact cap, often obscuring the eyes. Only the ears, the lower

part of the nose, and the muzzle are woolless, and these are covered with white, silky hair. The wool also extends down the legs to the hoofs. A large amount of yolk or oil is desired, as this is regarded essential to the production of the best quality of fiber, but in a great many cases it has been overdone. The skin is a beautiful shade of pink, the ideal color. The form is rather inferior; the neck is long, shoulders sloping, and the chest is narrow. The withers are thin, the spring of ribs only moderate, consequently the back is rather narrow. Behind, they lack development in the leg of mutton, being more or less "cat-hammed." This type became famous not only in the United States, but in foreign countries as well, and rams were shipped to Australia, South America, and South Africa. Many of the Vermont flocks have been disbanded, but shipments of Merinos are still made frequently from this State both to South Africa and South America. Some prominent men in early American Merino history were Stephen Atwood, of Woodbury, Conn.; Edwin Hammond, of Middlebury, Vt.; and William Jarvis, of Weathersfield, Vt. Robert Livingston also did a great deal in establishing the breed.

The Delaine Merino was developed through Ohio and Pennsylvania and to a lesser extent in Michigan and West Virginia. This type differs from the Vermont Merino in having a smoother body with few or no folds. They possess more size and fatten more readily than the type of American Merino mentioned above. The fiber is considerably longer and usually grades as a combing wool. It does not contain as much yolk as that of the American Merino. The Delaine breeders have endeavored to combine mutton qualities with wool, and their success is attested by the present popularity of this type.

There are several different families of Delaines. The most important of these are the Dickinson, the National, the Victor Beall, the Black Top, and the Improved Black Top.

Merinos in America are to-day divided into three classes, based upon the folds in their skin, fineness of fiber, their mutton qualities, etc., and are registered under these types. At the Columbian Exposition and again at the Louisiana Purchase Exposition in 1904, they were divided into two classes, A and B. Class C has since been added.

It must be admitted that there has been considerable confusion due to this classification. The fairs are not uniform in their specifications as to what comprises the different divisions, the judges are not all of the same opinion, and it is evident that the exhibitors have not the classification as clearly in mind as they should, since lightly folded A class sheep are sometimes shown with the B classes and heavily folded B's occasionally compete with A class sheep for honors. Another confusing condition is that the different classes do not breed true to type. A B-type ram may sire C-class lambs, or vice versa. Again the number of folds decreases with age, and a lamb that prop-

erly shows in the A class may belong to class B when it is a yearling or an aged sheep. The following paragraphs give the general idea of the different classes.

The A-type Merino is characterized by heavy folds or wrinkles upon the neck, breast, middle, and quarters and a complete covering of wool over the body and legs. The Vermont Merinos would usually fall into this class. Mature rams in breeding condition should weigh about 140 pounds and ewes about 100 pounds. Rams should shear close to 30 pounds of wool for one year's growth and ewes about 20 pounds. The fleece should be very dense, and the length of the fiber should be about $2\frac{1}{2}$ inches for one year's growth. The fiber should also be very fine, "crimpy," soft, and pliable. The yolk should be of a creamy color. It constitutes about 70 per cent of the fleece. Wool from this type grades as fine clothing or combing.

B-type Merinos should have folds upon the neck, breast, flank, and about the tail head. The covering of wool over the body and legs is not quite equal to that of the A type. Mature rams in breeding condition should weigh from 150 to 175 pounds and ewes from 100 to 115 pounds. Good rams shear in the neighborhood of 25 pounds and ewes about 15 pounds. The fleece is generally less dense than that of the A type. The fiber should be crimpy, soft, and pliable. It should measure from $2\frac{1}{2}$ to 3 inches in length. The yolk is preferably of a creamy color and comprises about 65 per cent of the weight of the fleece. The wool grades as fine clothing or delaine.

C-type Merinos should be perfectly plain or free from folds, unless to a very slight extent in the neck or breast. The Delaine represents this type. The head, legs, and body are not so well covered. Rams in good breeding condition should weigh about 175 pounds and ewes 125. A ram's fleece (12 months' growth) should weigh approximately 18 pounds and that of the ewes 11 pounds. The fleece is much less dense, containing about 20,000 fibers per square inch. The fiber is less crimpy and longer, measuring from 3 to 4 inches. The yolk is white in color and should comprise about 55 per cent of the fleece. The wool from this type grades as fine delaine or staple.

In most flocks of any material size all three classes or types are present, and these are crossed at the discretion of the breeder. For instance, if the ewes approach too closely to the angular A type, and their mutton qualities become markedly inferior, a ram is crossed upon them, of perhaps the C type, to remedy this and bring about a balance. If the opposite condition prevails, which is more often the case, an A-type ram might be used to improve the fleece. Some authorities hold that this is the sole purpose of the A type and that it is necessary to maintain a heavy fleece.

Despite the fact that the Merino has long since passed the height of its popularity, the Merino blood is more prevalent in America to-day

than that of any other breed. They have two principal strongholds in this country. The first and most important is the range country west of the Mississippi, and the second is the fine-wool section of Ohio, which also embraces parts of Pennsylvania, West Virginia, and Michigan.

On the range a hardy sheep that will withstand seasons of drought and scanty food, that will band together in large flocks while feeding, and that will produce a good fleece is desired. The Merino fills these requirements. But it is also desirable to raise a crop of mutton lambs on the range. The Merino is distinctly inferior for this purpose, and as it seems to be difficult to secure a mutton breed that will suit range conditions in itself, the alternative has been taken of using ewes of Merino foundation and crossing a mutton ram upon them. The Delaine-type ewe has been especially popular for this purpose.

In the fine-wool section of Ohio there are many purebred flocks of considerable size and note, and a large majority of the farmers' flocks are grade or purebred Merino. Much Vermont stock was taken to Ohio. The strongest fine wool of the world is produced in this region. The establishment of the Merino in this section has been to some extent due to the demand for breeding stock through the West. Now that the demand has decreased because of the reduction of the range and because of the Western States producing most of their own breeding stock, it seems possible that the Merino will remain and a type be developed that will more nearly fulfill the mutton requirements of the markets as they exist to-day. Of late years Merino ewes have been used for the production of "hothouse lambs."

The Merino breed has been hampered with a superabundance of record associations. Some of these have been founded upon certain strains of the breed, only sheep descended from these strains being eligible for registry. The confusion caused by crossing A, B, and C types and by the existence of numerous record associations is without a parallel in American live-stock history. The number of societies at the present time is not so great as formerly, as some of these have combined and others have dropped out of existence. The American & Delaine Merino Record Association, Delaware, Ohio; the Standard Delaine Merino Sheep Breeders' Association, Saline, Mich.; the Vermont, New York & Ohio Merino Sheep Breeders' Association, Delaware, Ohio; and the Michigan Merino Sheep Breeders' Association, Ann Arbor, Mich., are the principal remaining societies.

THE RAMBOUILLET.

The Rambouillet or French Merino breed was developed by the French Government for the purpose of securing a domestic supply of wool. In 1783, Louis XVI bought a large estate near the village of



FIG. 1.—CLASS A MERINO RAM.



FIG. 2.—CLASS A MERINO EWE.



FIG. 1.—CLASS B MERINO RAM.

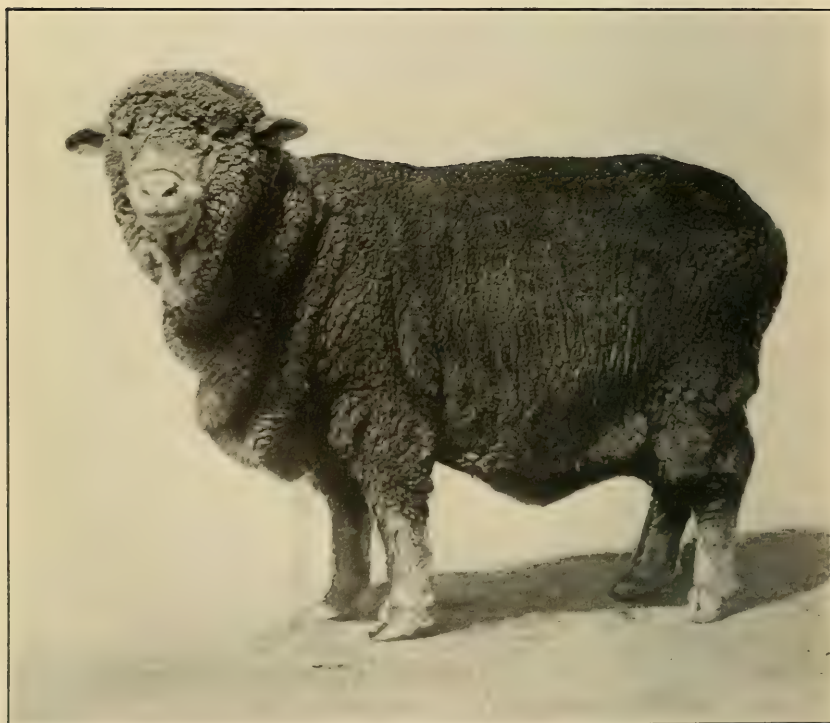


FIG. 2.—CLASS B MERINO EWE.

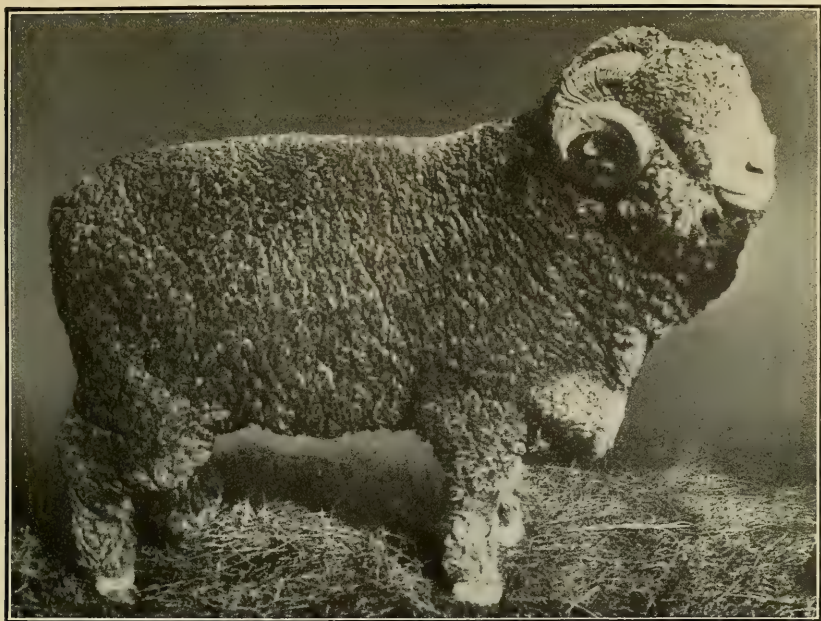


FIG. 1.—CLASS C MERINO RAM.



FIG. 2.—CLASS C MERINO EWE.



FIG. 1.—RAMBOUILLET RAM.



FIG. 2.—RAMBOUILLET EWE.

Rambouillet, which is located about 40 miles west of Paris. Three years later, M. Guilbert was sent to Spain to purchase foundation stock, and he selected individuals from the best flocks of the Kingdom. He landed 366 head at Rambouillet, and he made another purchase in 1799, but the latter importation lacked the quality of the first lot. These sheep were the nucleus of the breed.

It is claimed that they were developed entirely by selection. The French Government records of the evolution of the breed are remarkably complete and by far the most comprehensive in existence. Increasing the size seems to have been the principal consideration at the outset, and for a time constitution suffered at its expense. Later this was remedied, and the "French" Merino to-day differs from the Spanish in being more robust, larger, having a much superior form, and having fewer folds. They are better covered with wool, especially over the head, and the fleece is heavier and contains less oil and gum. The breeding qualities are also improved and early maturity developed to a greater degree.

All the credit for the development of the Rambouillet is not, however, due to the French Government. Private flocks were established in France at the beginning of the last century, and these sheep were later introduced into northern Germany. In the latter country the Von Homeyer flock at Ranzin, Pomerania, was one of great excellence. This flock was dispersed in 1898, upon the death of the owner. These sheep have also been introduced into Russia, Australia, Argentina, and the United States.

The career of the Rambouillet in this country has been somewhat checkered. They were first introduced by D. O. Collins, of Hartford, Conn., in 1840. Several other importations were subsequently made, but the breed did not prove very popular. They lacked in constitution and did not thrive. Interest in the breed waned until near the close of the century. In 1882, W. G. Markham, of New York, after visiting Europe and being highly impressed with the excellence of this breed in Germany, received a present of a ram and two ewes from the Von Homeyer flock. Two more importations from this flock followed in 1885 and 1891, respectively, and an exhibit of these sheep was made at the Columbian Exposition in 1893. They created a great deal of favorable comment and were called "Elephantine" Merinos because of their large size.

To-day this breed is widespread in its distribution. Their herding qualities, their improved mutton form, and their heavy fleeces have made them especially popular upon the range. Wyoming, Utah, Montana, Washington, California, Idaho, New Mexico, Texas, and Oregon are the most important Rambouillet States in this section. The breed is also quite widely distributed through the farming section. The superior breeding qualities of the ewes adapt them to the

production of "winter" lambs, and they are used to a certain extent for this purpose. Ohio, Michigan, New York, and Indiana are especially prominent Rambouillet States in the Middle West, but even here a large part of their popularity can be indirectly traced to the range demand. The highest prices recorded recently for American-bred sheep have been paid for individuals of this breed, and the superior quality of our home-bred Rambouillets has discouraged importations during recent years. Recently a number of choice shipments have been made to South Africa.

The Rambouillet is the largest of the Merino breeds. Mature rams in breeding condition should weigh from 175 to 225 pounds and should produce from 15 to 20 pounds of wool. Ewes under the same condition range from 130 to 160 pounds in weight and should shear 10 to 12 pounds. The staple should be from $2\frac{1}{2}$ to 3 inches long, but much of it falls short of this length. It commonly grades as fine clothing and combing. The rams usually have large spiral horns, but ewes should always be polled. An entirely polled type has been developed and has been given a trial by some prominent western breeders, but has not proved satisfactory. There has been an effort on the part of some breeders to establish a B and C type of Rambouillets, and classes were established for these at one of our State fairs. This movement should be discouraged, or it will eventually lead to as much confusion as there is at the present time in the different types of American Merinos. The plainer, or C, type of Rambouillet is called for in the West, while eastern breeders prefer the heavier, or B type, sheep. The cross between the Rambouillet and the American Merino has been termed the Franco-American, and a registry association has been organized to record them. They are criticised because of the fact that they do not breed true to type.

The American Rambouillet Sheep Breeders' Association was organized in 1889 at Pontiac, Mich. Up to January 1, 1914, it had recorded 73,305 head. The present headquarters are at Milford Center, Ohio. The International Von Homeyer Rambouillet Club Record was organized December 18, 1902, at Detroit, Mich., and has recorded about 500 head of sheep. Only those sheep that can trace their ancestry through unbroken lines to the Von Homeyer stock are eligible for entry in the latter association.

Following is the scale of points for the Von Homeyer Rambouillet.¹ The American association has no standard of excellence.

Density and length of wool are incompatible. Extreme density of fleece spoils physical development and mutton and wool merits. Stud sheep should be kept in moderate condition by food and exercise to insure constitution and prepotency. Fat covers a multitude of faults. The task is to breed for quality and quantity of wool and mutton equally at the smallest expense.

¹ Ranzin, 8, 2, 1894. v. Homeyer.

I. Constitution is the foundation:

- Shown by physical development, nutritive capability, good stomach, live weight, early maturity, form, and carriage;
- By prepotency to fix the type and constitution on offspring;
- By bone and strong frame, and a soft, loose, pink skin;
- By face and eye, denoting health and vigor;
- By well-set, sound teeth and mouth.

II. Mutton merits:

- Carcass heavy, broad, deep, long, with full and low thigh and flank, set on short, straight pillars.
- Chest and bosom projecting, broad and deep, shoulders flat and broad, back level, ribs round, hips and loin broad.
- Fleshy quarters, hams full and broad, gentle slope from dip to root of tail.

III. Wool merits:

- Length and evenness of staple, $2\frac{1}{2}$ to 3 inches at one year's growth, density of wool plant to insure 20 pounds for rams and 10 to 12 for ewe fleeces.
- Character and style of fleece, clear crimp with oily yolk.
- Uniformity in fineness all over, prima secunda sortiment.
- Covering of head, belly, arms, legs without kemp and jar.
- Absence of coarse jar in fleece.

IV. Characteristic appearance:

- Head broad on top, wide between ears, medium length.
- Horns curling, strong, standing in right angles at base.
- Eyes bright, clear, lids not impaired by folds and wrinkles that press on the lid and cause inflammation.
- Lachrymal glands without signs of inbreeding and inflammation.
- Nostrils large, free from pressure by wrinkles.
- Ears thick, large, and velvety.
- Nose covered with a cream-colored velvety coat.
- Neck short and broad, denoting vigor, with or without folds, my fancy being a belle cravatte.
- Dewlap well out in apron, covered with dense wool.
- Scrotum well woolled to the end.
- Pillars straight, wide apart, in good angle behind.

THE SOUTHDOWN.

The Southdown is probably the oldest breed of sheep in existence. They have been commented upon for centuries by prominent agricultural writers, and there is a distinct record more than 200 years old that refers to this breed and cites an incident where several flocks were entirely destroyed by a disease resembling smallpox.

The breed originated in the low range of hills in southeastern England, known as the South Downs, which extend through the counties of Kent, Sussex, Hampshire, and Dorsetshire.

The progenitors of the Southdowns were known as the Sussex sheep, and they were small, ill-shaped, horned sheep, having dark faces and lacking quality. Their fleeces were light but of good quality, and they had exceptional development of the leg of mutton.

The modern development of the Southdown has undoubtedly been effected entirely through selection. It is said that attempts were made to introduce new blood, but these have been unsuccessful.

Almost a century and a half of careful selection has improved the carcass, especially in development of the fore quarters, neck, and rump. Greater refinement has been attained and the horns have been eliminated. The names of John Ellman, of Glynde, and Jonas Webb, of Babraham, are inseparably connected with early Southdown history. Ellman bears the same relationship to this breed as Bakewell does to the Leicester, and he might fittingly be called the father of the medium-wool breeds.

The distribution of the Southdown is practically universal. They can be found in many parts of England outside of their native shires, and exportations have been made to almost every civilized country. The Southdown has been widely used in the development of the other medium-wool breeds of sheep, and there are very few, if any, of these that do not owe, either directly or indirectly, some part of their improvement to Southdown blood.

The first reliable record we have of Southdowns in this country is that of Dr. Rose's flock, in Seneca County, N. Y. In 1803 these sheep were reported as doing well. In all probability importations were made many years previous, and they have taken place almost continuously since that date.

The Southdown is the mutton sheep par excellence. There is no better combination of quality and beauty in the ovine world; hence their name, the "gentleman's sheep." This breed is remarkable in having a large number of wealthy admirers and breeders whose flocks have been of more than ordinary excellence, though even now, as a rule, the best specimens are imported from their native hills. The lawns of quite a number of famous country estates are kept closely cropped by these ovine aristocrats and they are also used upon the parks in some of the large cities.

Their distribution has been from the Atlantic to the Pacific and from Mexico to Canada, though they are not seen in as large numbers as some of the larger breeds. They have attained their greatest popularity in the South. In the spring-lamb region of Tennessee, Kentucky, and Virginia, Southdown rams are used almost exclusively. This country has few other sections where one breed has been adopted for a standard over so wide a range of territory. Other breeds have been tried here, and in some cases have produced larger lambs, but they lacked quality and condition and have not succeeded in supplanting the Southdown to any appreciable extent. The lambs of the latter attain a weight of 60 to 90 pounds when from 3 to 4 months old, and are ready for market the latter part of May, during June, and early July. Gains of from 1 pound to 1½ pounds per lamb per day are reported for short periods during the best growing season. The early lamb is the object sought after,

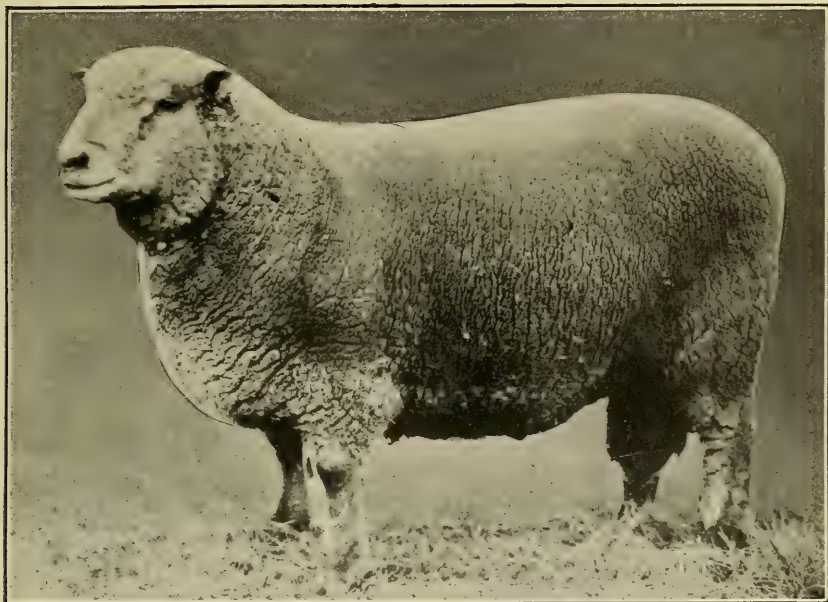


FIG. 1.—SOUTHDOWN RAM.

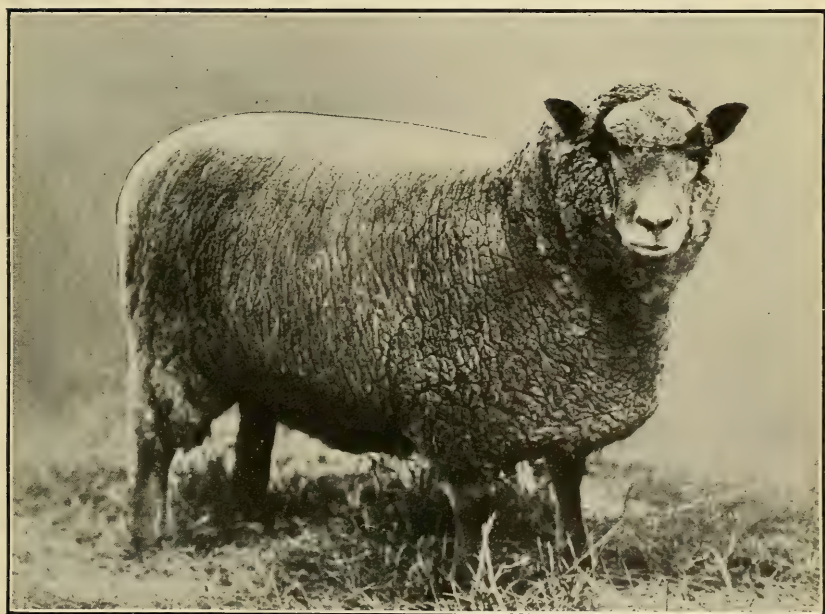


FIG. 2.—SOUTHDOWN EWE.



FIG. 1.—SHROPSHIRE RAM.

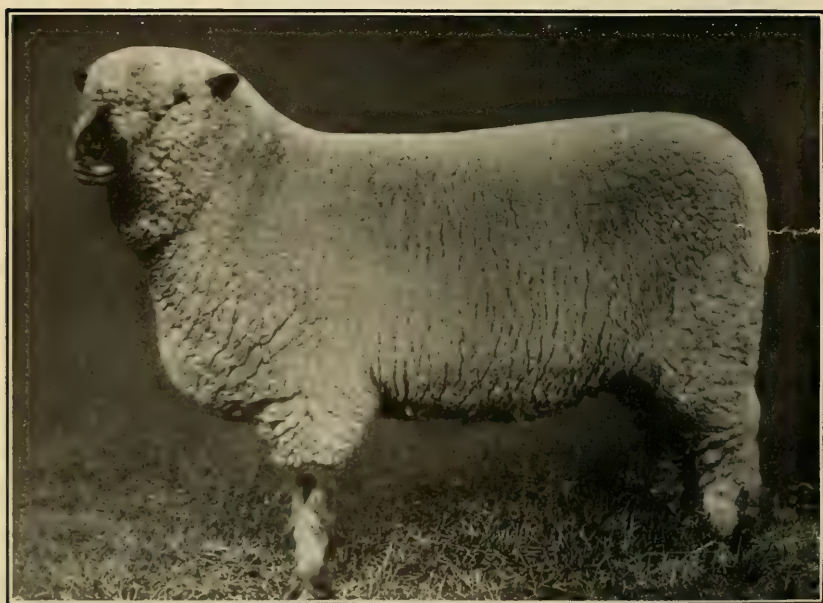


FIG. 2.—SHROPSHIRE EWE.

little attention being given to wool; hence the Southdown fills the place to perfection.

They are also popular in the Middle West and in New York. Here Southdown rams are frequently used for siring winter or hothouse lambs. Rams are also bred for the spring-lamb section of Kentucky and Tennessee. In the far West they have been used only to a limited extent, the objection to them being that they are too small and that their fleeces are too light.

The Southdown is the smallest of the mutton breeds. They are, however, remarkably compact; their deceptive weights causing them to be called "the big little sheep." Mature rams in breeding condition should weigh from 170 to 190 pounds and ewes from 125 to 130 pounds.

In the carcass contests at the International Show at Chicago since its inauguration in 1900 purebred, grade, and crossbred Southdowns have won 51 out of 84 possible prizes. Five out of eleven grand champions have also been of Southdown breeding.

The wool of the Southdown is of good quality, but the fleeces are not as heavy as might be desired. The ewes' fleeces should weigh from 6 to 8 pounds and the ram's from 10 to 12 pounds. The Government flock at the Morgan Horse Farm, Middlebury, Vt., has averaged approximately 7 pounds in weight of fleece during recent years, one of the breeding rams producing more than 12 pounds of wool. This wool graded very largely three-eighths and one-half blood combing, but in many flocks in this country clothing wool would predominate because of the shortness of fiber.

The breed is noted for its early maturity and its easy keeping qualities. Southdowns thrive upon pasture that would be entirely insufficient for the larger breeds. They are undeniably a short-pasture sheep. In fecundity they are fair, but not equal to the best. The Government flock mentioned before has given a 125 per cent lamb crop for ewes bred and 140 per cent for ewes lambing.

The most serious criticism that can be offered against the Southdown is that they are small and produce light fleeces. The superior quality of their mutton is not regarded high enough in many places in this country to offset these objections; hence the larger, heavier-fleeced breeds have to a certain extent occupied the place that they might otherwise fill. Years ago the dark-faced Southdown was preferred, but in recent years the lighter color is much more popular.

The Southdown Sheep Society of England published the first volume of their flock book in 1892. The American Southdown Association was incorporated June 23, 1882, at Springfield, Ill., where its office is still located. They had recorded up to January 1, 1914, 30,645 sheep.

The following is the standard of excellence for Southdown sheep:

	Points.
Head medium in size and hornless, fine, carried well up, the forehead or face well covered with wool, especially between the ears and on the cheeks, and in the ewe slightly dished.....	5
Lips and under jaw fine and thin.....	1
Ears rather small, tolerably wide apart, covered with fine hair, and carried with a lively back-and-forth movement.....	2
Eyes full and bright.....	3
Face a uniform tint of brown, or gray, or mouse color.....	3
Neck short, fine at the head, but nicely tapering, and broad and straight on top at the shoulders.....	4
Shoulders broad and full, smoothly joining the neck with the back.....	5
Breast wide, deep, and projecting well forward, the forelegs standing wide apart...	5
Back and loin broad and straight from shoulders to rump.....	7
Ribs well arched, extending far backward, the last projecting more than the others.....	6
Rump broad, square, and full, with tail well set up.....	6
Hips wide, with little space between them and last ribs.....	6
Thighs full and well let down in twist, the legs standing well apart.....	6
Limbs short and fine in bone, and in color to agree with the face.....	3
Forelegs well woolled and carrying mutton to the knees, but free from meat below..	2
Hind legs well filled with mutton and woolled to the hocks, neat and clean below..	2
Belly straight and covered with wool, the flank extending so as to form a line parallel with the back or top line.....	5
Fleece compact, the whole body well covered with moderately long and close wool, white in color, carrying some yolk.....	12
Form throughout smooth and symmetrical, with no coarseness in any part.....	9
General appearance spirited and attractive, with a determined look, a proud and firm step, indicating constitutional vigor and thorough breeding.....	8

100

THE SHROPSHIRE.

Although little more than half a century old, the Shropshire is to-day the most popular breed of medium-wool sheep. They attracted little attention prior to 1848, when they first received the name they now bear. They were first recognized in the prize lists of the Royal Show held at Wiltshire in 1857, but did not receive a place as a distinct breed until 1859, when the show was held at Warwick.

The breed originated in Shropshire, or Salop, as it is sometimes called, and the neighboring county of Stafford, in west-central England, Shropshire being bounded on the west by Wales.

Authorities are not all of the same opinion as to the exact origin of this breed, but it is quite generally agreed that the Morfe Common were the foundation stock, this being improved by the introduction of Southdown, Cotswold, and Leicester blood. The Longmynd, the Clun Forest, the Cannock Chase, and the Whittington Heath are also considered by some authorities as being involved in the evolution of this breed.

The Morfe Common were a small-horned sheep with black, brown, and spotted faces. Their carcasses weighed from 35 to 65 pounds, and the average weight of fleece was about 2 pounds. Their wool was of reputed good quality. The infusion of Southdown blood improved the mutton qualities and removed the horns. The Cotswold and Leicester blood increased the size and weight of fleece and introduced early maturing qualities. The introduction of new blood caused a lack of uniformity for a time, but this has been subsequently overcome by careful selection. Among the early improvers of the breed were Samuel Meire, of Berrington, and George Adney, of Harley.

From its home in Shropshire this breed has spread into practically every county in England. It may also be found in Scotland, Ireland, Russia, and nearly all other countries where improved sheep have been introduced.

An importation of Shropshires was made into Virginia in 1855, but the records do not state who imported them. Samuel Sutton, of Relay House, Md., brought over another lot in 1860, and since that time there have been many importations. In fact, few other breeds are being imported in greater numbers at the present time.

The profitable combination of wool and mutton the Shropshire represents has caused it to be known as the "farmers' sheep," and it has been especially popular in the farming sections of America. However, this breed has not only found a home under these conditions, but it has been used extensively in the West for crossing upon range ewes. Because of its wide range of adaptability and consequent popularity, it is doubtful whether there is a State in the Union that does not possess flocks of this breed. The Shropshire is also prominent in the show ring, as attested by the large classes exhibited. They usually overtop any other breed in respect to numbers, and there have been instances where they outnumbered all other breeds combined. It is a source of considerable satisfaction to American Shropshire breeders to know that their best sheep are not surpassed in excellence by any imported. This is also a tribute to the breed, as it indicates that the Shropshire does not deteriorate when removed from its native home, but maintains its type and soon becomes acclimatized. The winnings at the International Live Stock Exposition, tabulated on pages 57 and 58, indicate to some extent the prominence of the breed.

At present the Shropshire is an early maturing breed of pronounced fecundity. They are medium sized, rams weighing from 175 to 250 pounds and ewes from 140 to 180 pounds. Their wool is of good quality and weight, fleeces ranging from 8 to 15 pounds. One of the best ewe flocks in this country, comprising over 200 head, produced 10.31 pounds per head, which is a very good average. From data

secured from leading Shropshire breeders, an average of 8 to 9 pounds is considered very satisfactory. Most Shropshire fleeces grade three-eighths blood combing or clothing.

In the past the Shropshire has been unfavorably criticized for being light in the hind quarters, but notable improvement has been accomplished in this respect. Black fiber and dark spots on the skin are other objections that have been noted in inferior individuals. When in high condition, especially when carelessly fed, there is a tendency for the Shropshire to become "patchy," but this is true of all breeds to a certain extent.

The English Shropshire Sheep Association was founded in 1882. It published the first volume of its flock book the next year, and this was the first British sheep record to appear. The American Shropshire Breed Association has been in existence since February, 1884, when it was organized at Lafayette, Ind. It is the strongest live-stock organization in existence, and up to January 1, 1914, it had registered 385,411 head of sheep. The offices are still located at Lafayette. The following are the points of excellence and scale of points for the breed:

	Points.
1. Type and general appearance.....	30
An alert, attractive, and stylish appearance, showing at a glance the true characteristics of the Shropshire.	
2. Form and constitution.....	35
Head: To impress at once the Shropshire characteristics.	
Heads of rams: To be masculine, as indicated by a broad nostril; short; broad between ears and eyes.	
Neck of rams: Short and muscular, fitting into shoulders in graceful outlines.	
Heads of ewes: To be feminine in appearance, medium in length, but not delicate.	
Neck of ewes: Not so strong as in the ram. In all cases head and face nicely covered with wool; ears, short and erect; eyes, bright; color of face, brown to a clear dark (not sooty black).	
Body: Well proportioned, with shoulders so placed as to fit in evenly to a deep wide brisket. A full heart girth; broad level back; ribs well sprung, with straight underline; loins thick fleshed; fore and hind flank deep, a low-coupled twist, and full leg of mutton.	
Legs: Brown to clear dark color (not sooty black); well set apart; short and straight, with strong upright pasterns.	
Size: When fully matured and in proper breeding condition, rams should weigh not less than 175 to 250 pounds and ewes not less than 140 to 180 pounds.	
3. Fleshing.....	25
While the body should be well formed, with the full outline pleasing to the eye, yet it is the quality and quantity of flesh, not fat, which gives value to the carcass. Therefore the parts furnishing the high-priced cuts should be fully developed.	
The back, loins, and legs should be so fleshed as to show a large percentage of flesh compared with the other parts of the body; at the same time symmetry must prevail throughout.	
Strong bone in legs conformable with size of body usually goes with a large proportion of lean meat to fat in the finished carcass.	

Points.

10

4. Fleece and skin..... 10
 Fleece of good length, elastic to the touch, medium fine and slightly crimped, free from black fiber and hairiness. Ram's scrotum to be well covered with wool.

Rams should shear 8 to 15 pounds of wool and ewes 7 to 11.

Skin to be a bright cherry or clear color and comparatively free from dark spots.

Objections:

Long, narrow head, with long ears and neck; long legs; black wool on head to any noticeable extent; failure of wool to meet closely at the junction of face-wool and on checks; white spots on face and legs; crooked spine; light flanks, with long, weak pasterns; spotted skin; narrow chest, showing lack of constitution.

Disqualification for registry:

Such lack of type as to render it doubtful to a breeder what the breed is; horns or stubs, not scurs. Heads quite bare of wool.

THE HAMPSHIRE.

The native home of the Hampshire sheep is in the county of the same name, which is located in south England, bordering upon the English Channel.

The breed was evolved about three-quarters of a century ago and for a time was known as the West County Downs. They were first exhibited at the Royal Show at Oxford in 1837 under this name. They did not receive a class of their own until the show was held at Salisbury in 1857.

The Hampshire of to-day is the result of the amalgamation of two native types, into which had been introduced the blood of one or more improved breeds. These two types were known as the Wiltshire and the Berkshire Knots.

The Wiltshire sheep were native of North Devon, Somersetshire, Buckinghamshire, and Berkshire. They were the largest fine-wool sheep of Britain. They were white-faced, horned, slow-maturing sheep of rather inferior mutton qualities. They undoubtedly had been in existence for centuries, for it is said that the old Roman woolen mills at Winchester were supplied with wool from these sheep. They were also known as "crooks," because of the peculiar shape of their horns.

The Berkshire Knots were also a horned type, very rugged and hardy, but with black faces and legs.

The two native types were crossed and recrossed with Southdowns. Along with the improvements introduced, this decreased the size, which was remedied by selecting the largest ewes and rams for breeding purposes. Some Cotswold blood was also introduced by at least one early breeder, Mr. John Twynham.

By 1835 the native types had been largely covered up in a "modified type of Southdown," though they still retained some of the characteristics of the older breeds, especially in size and quality of

wool. When exhibited in 1840, they were smaller, less compact, narrower in front, and lighter in color than the Hampshire of to-day.

The present breed owes much of its excellence to the work of William Humphrey, of Oak Ash, Newberg, and James Rawlence, of Bulbridge, Wilton, Hampshire.

Flocks of Hampshires can be found to-day in Wiltshire, Berkshire, Dorsetshire, Sussex, and Surrey, besides their native county. At Isley, in Berkshire, as many as 33,000 Hampshires have been shown at the fair. Exportations have been made to the United States, Canada, Mexico, South America, South Africa, and to many countries of Europe.

Importations of Hampshires were made to Virginia prior to the Civil War, but in the strife that followed they were neglected and all records were lost. It is said that the dark-faced sheep of North Carolina are descended from these Hampshires.

In 1865, Thomas Messinger, of Great Neck, Long Island, made an importation. For more than a quarter of a century very few Hampshires were brought over, but about 1880 interest in the breed was revived and importations became more frequent. During the past few years they have been especially popular, and larger importations have been made of Hampshires than any other breed. One importation numbered over a thousand ewes.

No breed of sheep will give more satisfactory returns than the Hampshire, if accorded good care and given plenty of feed. Neither will any other breed deteriorate more rapidly, if these are denied. They are unable to rustle for themselves to the extent of some other breeds, consequently they do not thrive upon broken or scanty pasture. They are especially adapted to an intensive system of farming, such as hurdling upon green forage crops, rape, turnips, etc.

Purebred flocks of Hampshires are confined largely to the States of Kentucky, Ohio, Indiana, Illinois, Michigan, and New York in the East and Idaho, Montana, Wyoming, and Missouri in the West. Hampshire rams are used quite widely upon the range for crossing upon ewes of other breeds for the production of market lambs. The Hampshire lambs are large; they grow rapidly and attain their greatest perfection while comparatively young—the reason for their wide popularity. In the East the rams are frequently used for siring “hothouse” lambs.

The Hampshire, with possibly one exception (the Oxford), is the largest of the Down breeds, and it is excelled in size only by the Lincoln and the Cotswold among the long wools. Hampshire rams generally range in weight from 225 to 275 pounds and the ewes from 175 to 200 pounds. The popularity of the Hampshire lamb speaks for the mutton qualities of this breed.

The head of the Hampshire is very characteristic. The face is black, and they have a Roman nose. The ears are large, somewhat pointed,



FIG. 1.—HAMPSHIRE RAM.



FIG. 2.—HAMPSHIRE EWE.

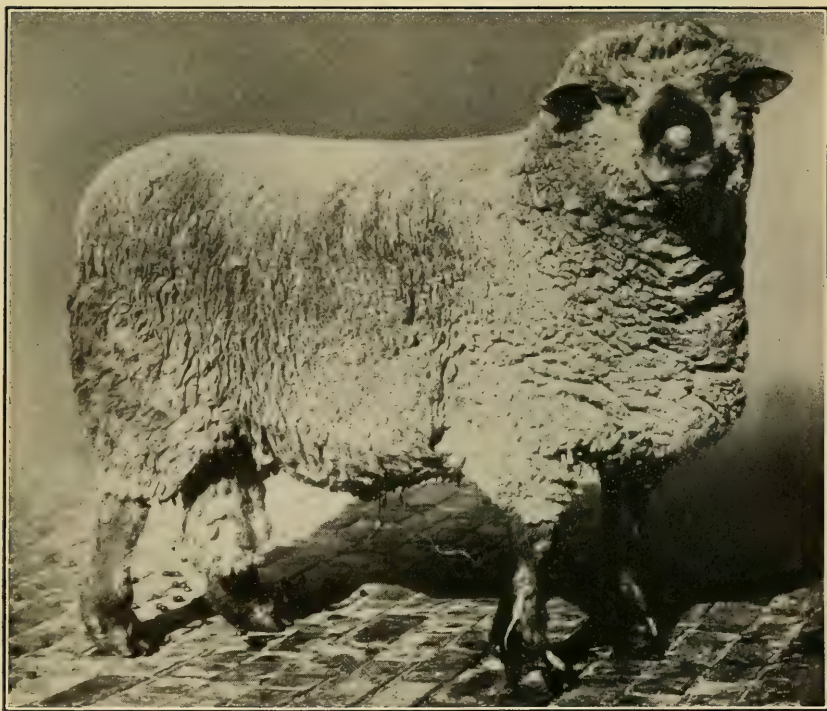


FIG. 1.—OXFORD RAM.



FIG. 2.—OXFORD EWE.

and extend out almost at right angles from the head. The fleece is of medium quality and not as heavy as is desired, usually ranging in weight from 6 to 8 pounds, and the greater portion of the wool grades quarter and three-eighths blood combing.

The Hampshire is unexcelled in early maturity, the rams commonly being used for breeding purposes when from 7 to 9 months old. The fecundity of this breed is very creditable, though some of the others surpass it slightly in this respect.

The principal criticism of the Hampshire is that they require the best of attention or they soon become "weedy." They require an abundance of food and are not satisfactory where pastures are short or broken.

The Hampshire Down Sheep Breeders' Association of England was organized during December of 1889 at the Agricultural Hall, Islington, during Smithfield week. The Hampshire Down Breeders' Association of America was organized November 4, 1889. To January 1, 1914, 49,640 sheep have been registered by this association. The secretary is located at Coldwater, Mich. The following is the standard of excellence of the American association:

HEAD AND LEGS.

Head: Moderately large, but not coarse; well covered with wool on forehead and cheeks.

Nostrils: Wide.

Color (head and legs): Dark brown or black.

Eyes: Prominent and lustrous.

Ears: Moderately long and thin, and dark-brown or black color.

Legs: Well under outside of body; straight, with good size of bone; black.

NECK, SHOULDERS, AND CHEST.

Neck: A regular taper from shoulders to head, without any hollow in front of shoulders; set high up on body.

Shoulders: Sloping, full, and not higher than the line of back and neck.

Chest: Deep and full in the heart place, with breast prominent and full.

BODY.

Back: Straight, with full spring of rib.

Loin: Wide and straight, without depression in front of hips.

Quarters: Long from hips to rump, without sloping, and deep in thigh; broad in hips and rump, with full hams; inside of thigh full.

SCALE OF POINTS.

Head: Size and shape, 5; ears and eyes, 3; color, 5; legs and feet, 2.....	15
Neck, shoulders, and breast: Neck, 5; shoulders, 10; chest and breast, 15.....	30
Body: Back and loins, 15; rib, 5.....	20
Quarters: Length, 10; width, 10; twist, 5.....	25
Wool: Forehead and cheeks, 2; belly, well covered, 3; quality, 5.....	10
Total.....	100

THE OXFORD DOWN.

The Oxford Down originally was a crossbred sheep, having developed from the direct crossing of well-established types. Although improved blood of other breeds has been used in establishing most of our present ones, evolving an entirely new breed by direct crossing is comparatively rare, the Corriedale of New Zealand and Australia being the only other example.

The initial crossing that eventually resulted in the establishment of the Oxford breed took place about 1833 in Oxfordshire. Cotswold rams were used upon Hampshire ewes and some Southdown blood is also said to have been introduced. The object was not the establishment of a new breed but improvement in the existing breeds.

These crossbred sheep first appeared at the Windsor Royal in 1851 under the name of Down Cotswold. About 1857 their name was changed to Oxfordshire Downs. They did not receive a distinct place at the Royal until it was held at Battersea in 1862. As was to be expected, this breed was at first characterized by a striking lack of uniformity, the judges of the Royal criticizing the exhibits of the years of 1862, 1865, and 1868 very unfavorably for this defect. During the next 10 years there was a very great improvement in this respect, the type becoming much more permanent. Mr. Samuel Druce, of Eynsham, Oxford, and Mr. William Gillette, of Southhigh, were actively identified with the early development of the Oxford breed.

The Oxford has extended its sphere of usefulness from its native shire to many parts of England, Scotland, Ireland, and Wales. It is especially popular for crossing purposes along the "border" of the first two countries. This breed has also been introduced into many countries of Europe, North and South America, Australia, and New Zealand, in which countries it has generally met with success.

The first importation of this breed of sheep to America was made by Clayton Raybold, who brought them to Delaware in 1846. This was in the early days of the breed, and they were still known as Cotswold crossbred sheep. In 1853 William C. Rives brought some into Virginia, and R. S. Fay, of Lynn, Mass., made an importation the same year.

In the United States the greatest number of purebred Oxford flocks are found in New York, Ohio, Michigan, Wisconsin, Illinois, and Iowa. In the West there are some purebred flocks, but here the breed is valued chiefly for crossing purposes. Indeed, many flocks are maintained for supplying the range with rams, as the Oxford, because of its large carcass and heavy fleece, has been very popular during the last decade. Wherever the pasture is abundant the Oxford gives satisfaction, but it is in no sense a short-pasture sheep and does not usually thrive under the latter conditions.

The Oxford is generally conceded to be the largest of the medium-wool breeds. Mature rams range in weight from 250 to 350 pounds

and ewes from 180 to 275 pounds. The fleece is heavy, but it derives most of its weight from its length, as it is somewhat open in character, due to Cotswold blood. Superior Oxford flocks should shear 12 pounds of wool, on an average, of quarter and low quarter blood combing wool, though Oxford fleeces occasionally grade as braid wool.

The breed does not mature so early as some of the smaller ones, but they are at least average in this respect. Their fecundity is also about the average.

Objections to inferior Oxford Downs are open fleeces, dark spots on the skin, and occasional black fiber.

The English Oxford Down Breeders' Association was established in August, 1888. The American Oxford Down Record Association drew up its articles of incorporation at Cincinnati, Ohio, in January, 1882, after having met at least once during the previous year. The number of sheep recorded by this society up to January 1, 1914, is 67,280. The office of the secretary is now at Hamilton, Ohio. The following is the scale of points of the American Oxford Down Record Association:

BREED TYPE FOR ANIMALS.

	Points.
Form of a good general appearance, made by a well-balanced conformation, free from coarseness in any part, and showing good style both at rest and in motion.....	15
Head of moderate length and width between the ears and between the eyes, and well covered with wool over poll and down to the eyes. Color of face an even dark gray or brown, either with or without gray spot on tip of nose.	6
When fully matured and in good condition, rams should weigh 250 to 350 pounds; ewes, 180 to 275 pounds.....	5
Ears medium size, not too thick and of an even brown or dark gray color.....	2
Legs short, strong in bone, flat and of even dark gray or brown color, placed squarely under the body and well apart.....	2
	30

CONSTITUTION.

Large around the heart and wide and full in the chest.....	10
The movement must be bold and vigorous.....	5
Eyes bold, prominent, and bright.....	4
Skin bright pink in color.....	3
Neck strong and muscular in rams and well set on in both sexes.....	3
	25

MUTTON FORM AND QUALITY.

Wide and straight on top of shoulders, back, loin, and rump, from base of neck to tail.....	15
Full shoulders and thighs, well meated both inside and outside.....	5
Flanks well filled and strong so as to make the lower lines of the body as straight as possible, and the side lines straight or rather full.....	4
The whole carcass evenly covered with good, well-marbled meat.....	6
	30

WOOL.

Fleece of moderate length, close and of even quality, covering the whole carcass well, and free from black patches upon the body, neck, or head.....	15
Total.....	100

THE DORSET HORN.

The Dorset Horn, like the Southdown, is an extremely old breed that has been developed largely through selection. For several centuries there had existed in the county of Dorset in southern England a type of sheep that were coarse, small, and light of carcass, especially in fore quarters; but with broad, deep loins. They had dark noses and both sexes were horned. In Somerset was a larger, lankier type, producing longer wool and noted for their large lambs. They had white faces and pink noses. These types were probably the ancestors of the Dorset Horn.

Little improvement was wrought in this breed until near the middle of the last century, and as mentioned in the preceding paragraph this improvement was effected through well-directed selection. Crossing was tried by a few breeders with both the Devonshire Knots and the Leicesters, but the attempts to introduce foreign blood resulted in failure.

Not a little credit for the latter development of this breed is due to Richard Seymour, of Bradpole, who began improving his flock about 1830. Mathew Paul, of Burstock, was another early Dorset breeder of prominence.

Although the sheep of Dorset and Somerset have long been recognized as distinct in type from those of surrounding counties, they were not assigned a place as a separate breed until 1862, when they were shown as such at the Royal at Battersea.

The stronghold of the Dorset Horn is still in its native district of Dorset, Somerset, and Devon. In the former two counties it is the predominant breed. The section about Dorchester and the Isle of Wight possess many flocks of marked excellence. Small flocks are scattered over England, Scotland, and Ireland, but their distribution does not approach that of the more popular down breeds. They have also been exported to the Continent and to America.

It is said that Dorset Horn sheep were first introduced into Virginia prior to 1882, but information as to where the shipment was made and who made it is lacking. Some representatives of this breed were shown at the fat stock show at Chicago in 1885, and two years later William Davey, of Lockport, N. Y., purchased some individuals of this breed from Valency E. Fuller, of Canada. The same year direct importations were made from Great Britain by A. Thayer, of Hoosick Falls, and E. F. Boroditch, of Massachusetts. In 1889, T. S. Cooper, of Pennsylvania, made a large importation, consisting of 153 head.

Dorsets can be found to-day in at least 32 States of the Union. New York, Ohio, Illinois, West Virginia, Massachusetts, Pennsylvania, Indiana, and New Jersey, in the order named, have the largest number of purebred flocks, and most of the other flocks are to be found in the eastern half of the country.

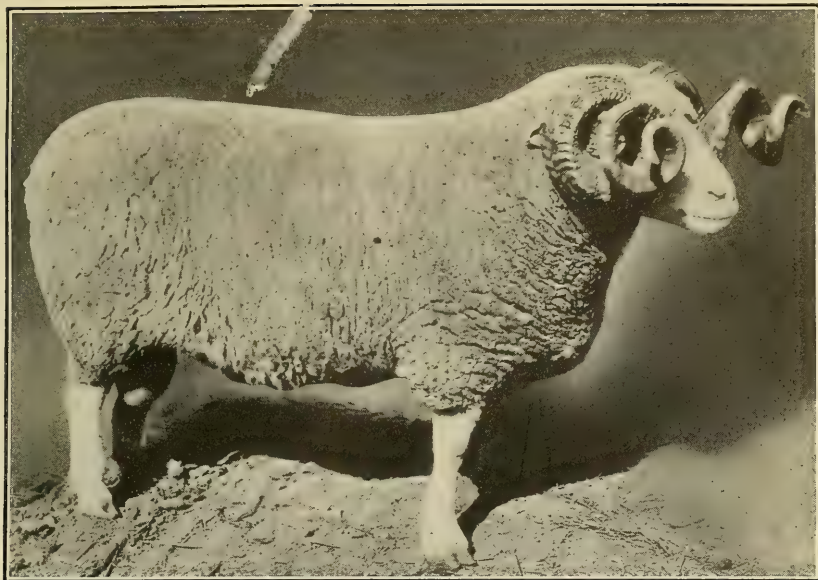


FIG. 1.—DORSET RAM.

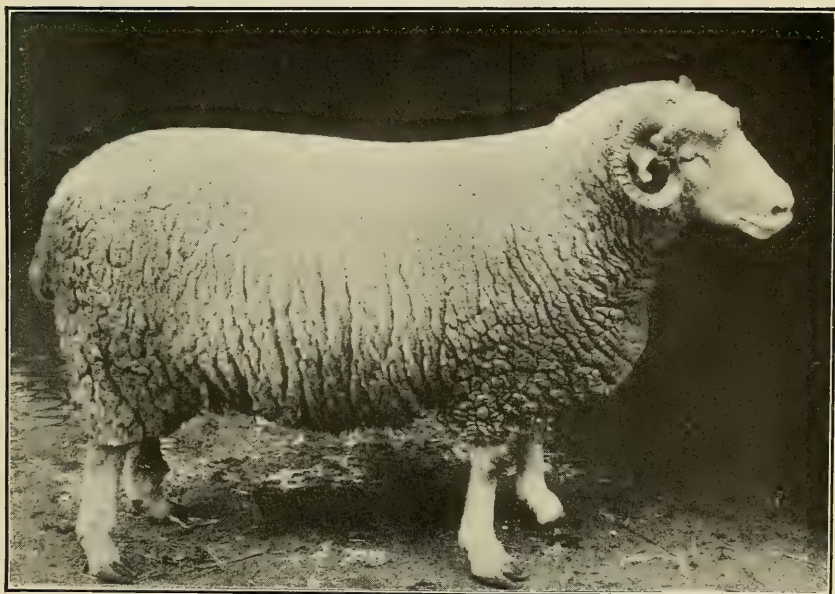


FIG. 2.—DORSET EWE.



FIG. 1.—SUFFOLK RAM.



FIG. 2.—SUFFOLK EWE.

There are very few Dorset flocks west of the Mississippi. Dorset wethers lack the finish characteristic of the lambs. Their fleece is not as heavy as is desirable. The lack of higher development in these two respects will probably prevent their ever becoming popular upon the range.

The Dorset Horn is a medium-sized, somewhat rangy, white-faced breed, both sexes being horned, as the name would indicate. There is considerable variation in the size of American Dorsets, but rams in breeding condition should weigh from 200 to 225 pounds; ewes from 150 to 175 pounds. Their fleeces lack somewhat in weight, but are of excellent quality. The fiber is very white, and discolorations are practically unknown. Ewes produce from 6 to 7 pounds and rams from 8 to 10 pounds of wool. Twenty-five samples of Dorset fleece were graded upon the Philadelphia market, for the United States Department of Agriculture, 15 of which were three-eighths blood combing and the other 10 quarter blood combing wools.

The Dorsets are probably the most fertile of all the mutton breeds of sheep, ewes frequently producing twins and triplets, and occasionally quadruplets. American breeders report from 140 to 175 per cent lamb crop. The ewes will breed either in the spring or fall, and it is claimed that they will produce two crops of lambs per year, but it is unlikely that this can be successfully accomplished, as most American breeders of prominence condemn the practice as being injurious to the ewes. The ewes are excellent mothers and usually have ample milk for their lambs, whether they be singles, twins, or triplets. In the United States a large percentage of the ewes lamb in the fall, many breeders having the entire crop dropped at this time. In their native shire the ewes were formerly used for dairy purposes.

The breed matures early, the lambs growing rapidly and exhibiting a bloom that they often do not retain during the wether stage.

Dorset ewes are very highly regarded for the production of "hot-house" lambs, and the grades are considered even better for this purpose than the purebreds. The East, with its large cities and consequent favorable market facilities, is especially adapted to the production of this product, which explains the distribution of the breed in this section.

The light shearing qualities and the fact that the Dorset is a hard feeder are the main objections to this breed. Dorset lambs are as a rule excellently fleshed, but the criticism has been made that the wethers are deficient upon the shoulders and back. The breed is also criticized for being deficient in heart girth. This is especially true of the rams.

The Dorset Horn Sheep Breeders' Association of England was founded in 1891. The American Dorset Horn Breeders' Association was founded the same year, but has been inactive of late years. The

Continental Dorset Club was founded in 1897, and up to January 1, 1914, it had recorded 15,030 sheep. The secretary's address is Mechanicsburg, Ohio. The following is the scale of points of the breed as adopted by the last-named organization:

SCALE OF POINTS.

Head: Neat, face white, nostrils large, well covered on crown and under jaws with wool.....	5
Horns: Small and gracefully curving forward rather close to jaw.....	5
Eyes: Prominent and bright.....	2
Ears: Medium size, covered with short white hair.....	2
Neck: Short, symmetrical, strongly set on shoulders, gradually tapering to junction of head.....	5
Shoulders: Broad and full, joining neck forward and chine backward with no depression at either point (important).....	15
Brisket: Wide and full, forward, chest full and deep.....	8
Fore flank: Quite full, showing little depression behind shoulder.....	8
Back and loin: Wide and straight, from which ribs should spring with a fine, circular arch.....	10
Quarters: Wide and full, with mutton extending down to hocks.....	10
Belly: Straight on under line.....	3
Fleece: Medium grade, of even quality presenting a smooth surface and extending over belly and well down on legs.....	12
General conformation: Of the mutton type, body moderately long; short, stout legs, placed squarely under body; skin pink; appearance attractive.....	15
Total.....	100

SUFFOLK DOWN.

The Suffolk Down is a comparatively new breed of sheep that has originated in Norfolk and neighboring counties of southeastern England. The Suffolks owe their origin to the crossing of Southdown and possibly Hampshire rams upon the Old Norfolk breed. These latter sheep have been described as being active, robust, upstanding, with black faces and legs, and horned in both sexes. They were very prolific and produced fleeces of fine, soft wool averaging about 3 pounds in weight.

The Southdown blood improved the carcass, increased the early-maturing qualities, and removed the horns. It is claimed that no foreign blood was introduced after 1850. Separate classes were made for the breed at the Suffolk show in 1859, when they received their present name. Prior to this date, they had been known as Southdown-Norfolks, and locally as Blackfaces. The breed was not considered established well enough to merit a class at the Royal Show until the meeting of 1886. George Dobito, of Ludgate, Suffolk, stands preeminent among the early improvers of this breed, and he began work about 1850.

The extent of distribution of the Suffolk does not approach that of the other Down breeds, but they are fairly common in the counties of

Norfolk, Suffolk, Cambridge, Essex, and Kent, and are found in scattered flocks over other parts of England. The excellent quality of their mutton and their high dressing percentage have won them an enviable position upon the English mutton market, and the prizes won by this breed in carcass contests at the leading shows are especially numerous. The newness of the breed and the fact that they have not been intensively advertised are factors in their limited distribution, but importations have been made into the countries of Holland, Germany, France, Spain, and Saxony, of Europe, and to Australia, New Zealand, South Africa, and North and South America. In the latter country they are quite popular for crossing upon Merino ewes because of the excellence of the resulting lambs.

The first importation of Suffolk Downs into this country was made by Mr. M. B. Streeter, of Brooklyn, N. Y., in 1888. Other importations have since followed. Purebred Suffolks have been recorded from 16 States, Iowa, Indiana, Illinois, the Virginias, and New York having the largest number of flocks. The fact that only one or two shows in this country have distinct classes for this breed indicates that the Suffolk has not yet secured a very firm foothold in America.

The Suffolk is a rather active, large, upstanding sheep, rams weighing from 200 to 240 pounds and ewes from 150 to 200 pounds. They are characterized by their jet black head and legs, being darker than any of the other breeds in these points. The ears are pointed and are frequently carried pointing upward and backward from the head. They have no wool on the face, or upon the legs from the knees and hocks downward. Though upstanding in appearance, these sheep dress out to good advantage. In 1903 a Suffolk won first in the carcass contest at the International at Chicago. The mutton is of excellent quality, closely approaching that of the Southdown. Their fleeces are light, but the wool is soft and of fair quality, grading low three-eighths and quarter blood combing. Flocks have been reported averaging 9 pounds of wool, but it is probable that the average is considerably below this figure.

The fecundity of the Suffolk is very high, ranking near the top. They are an early-maturing sheep, as indicated by the wide use of the ram lambs for breeding purposes.

The most serious criticisms of the Suffolk are their light fleeces and upstanding appearance. They are fair in feeding qualities, and if the prejudice against their lanky appearance can be overcome, there is no reason why they should not become much more popular in this country.

The English Suffolk Down Sheep Society was organized in 1888 for the purpose of registering purebred flocks. The American Suffolk Flock Registry was founded in 1892 with headquarters at Des Moines, Iowa. There were 2,264 Suffolks recorded in the United States and Canada up to January 1, 1914.

The following is the scale of points of the Suffolk Sheep Society of England:

	Points.
Head: Eornless; face black and long, and muzzle moderately fine, especially in ewes. (A small quantity of clean, white wool on the forehead not objected to.)	
Ears, a medium length, black and fine texture. Eyes, bright and full.....	25
Neck: Moderate length and well set (in rams stronger, with a good crest).....	5
Shoulder: Broad and oblique.....	5
Chest: Deep and wide.....	5
Back and loin: Long, level, and well covered with meat and muscle; tail broad and well set up. The ribs long and well sprung, with a full flank.....	20
Legs and feet: Straight and black, with fine and flat bone. Woolled to knees and hocks; clean below. Fore legs set well apart. Hind legs well filled with mutton.....	20
Belly (also scrotum of rams): Well covered with wool.....	5
Fleece: Moderately short; close, fine fiber without tendency to mat or felt together, and well defined, i. e., not shading off into dark wool or hair.....	10
Skin: Fine, soft, and pink color.....	5
Total.....	100

THE CHEVIOT.

The origin of the Cheviot is obscure. There is an old legend to the effect that they came out of the sea, presumably having swam ashore from one of the wrecked ships of the Spanish Armada. Another theory is that they are the sole representatives of an old type that in ages past occupied a large portion of Scotland. Flocks of the breed are said to have been maintained by the monks of this region during the Middle Ages on the pasture lands surrounding the monasteries. The breed is an old one at any rate. They received their present name about 1791, but are locally known as the "long sheep" in contradistinction to the "short" or Black-faced Highland sheep.

As stated before, the Cheviot is an extremely old breed. As early as 1757, Mr. Robson, of Belford, purchased some Lincolnshire rams to use upon his flock and by so doing made considerable improvement in the breed. Edminstoun and Kerr, other eminent Cheviot breeders, followed the same practice and likewise got good results. Later, Leicester blood is said to have been introduced, carrying with it the improvements that this breed almost invariably effected, namely, early maturity and improvement of form. For a long term of years the breed has been kept pure, any later attempts to introduce new blood having failed.

The distribution of the Cheviot to-day is through the counties of Roxbury, Dumfries, Peebles, and Sutherland, in Scotland, and Northumberland, in England. At the beginning of the last century the Cheviot became very popular and crowded back the Black-faced Highland to a considerable extent. The principal reason for this was that the wool of the former was in high demand, and the Cheviot was consequently more profitable than the Black-face.

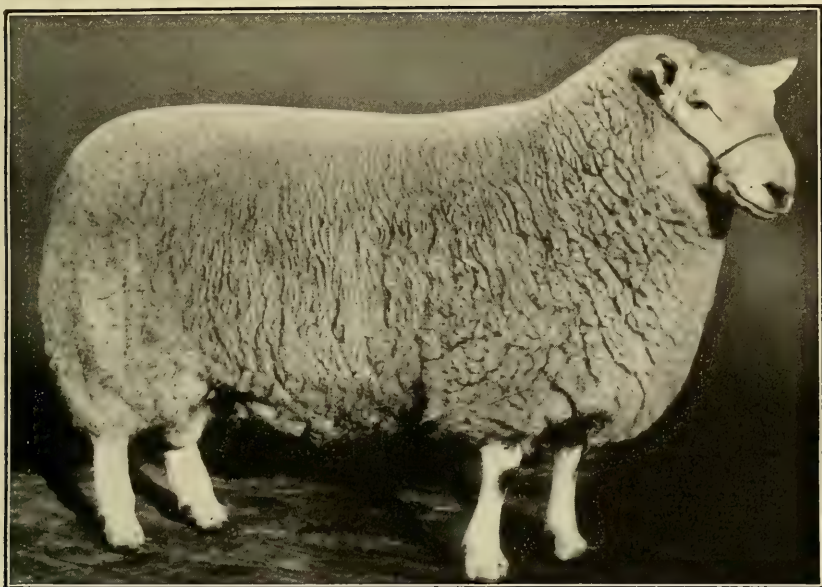


FIG. 1.—CHEVIOT RAM.

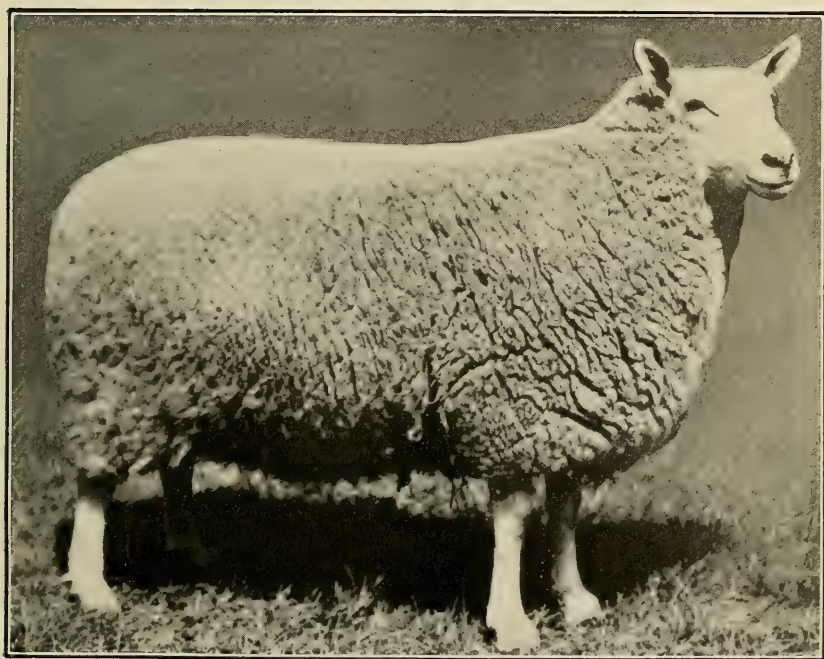


FIG. 2.—CHEVIOT EWE.



FIG. 1.—TUNIS RAM.



FIG. 2.—TUNIS EWE.

Bad weather for several years reduced the lamb crop of the former breed to such an extent that the Black-face soon regained its prestige, because of its greater hardiness in this respect. The breed is now extensively used in cross breeding upon mountain sheep. Cheviots are also being bred in a limited way in Iceland, and they have been introduced into New Zealand.

Cheviots were brought into Canada about 1825. Mr. Robert Youngs, of Delphi, Delaware County, N. Y., made the first importation into the United States in 1838. Another importation into the same county followed shortly afterwards, and other shipments were brought over, but active interest did not manifest itself in the breed until about 1880.

The Cheviot flocks of this country are entirely confined to the farming sections. New York, Indiana, Illinois, Wisconsin, Pennsylvania, and Ohio have the largest numbers. New York has probably as many as all the other States named.

Some years ago it was thought that the Cheviot would prove popular upon the range, but for some reason, probably the fact that they do not herd well, they have failed to establish a foothold in the West.

The Cheviot is a rather small, hardy breed of pronounced grazing qualities. Among their native hills they graze the year around, pawing aside the snow to find the grass, if necessary. Mature rams in breeding condition should weigh from 175 to 200 pounds and ewes from 140 to 160 pounds. The stylish carriage and comely manner of the Cheviot has characterized them as the "ladies'" sheep.

The head and ears are free from wool and covered with short, white hair. There is a distinct ruff or collar about the neck. The legs are woolless.

The mutton is of good quality and the wool is exceptionally white, containing little yolk or oil, and averages about 5 inches in length. The fleeces are, however, rather light, rams producing from 7 to 11 and ewes from 6 to 9 pounds, as a rule, of quarter blood combing wool. The fertility of the Cheviot is quite high, twins being frequent, and the ewes are very good mothers.

Wonderful improvement has been made in American-bred Cheviots during the past few years. Owing to this fact very few Cheviots have been imported.

Like most of the mountain breeds, the Cheviot is light in the fore-quarters. They are also subject to the criticism of not being very well fleshed over the back and shoulders. "Scurs" or stubs of horns and reddish or tan colored hair upon the face sometimes crop out in inferior individuals.

The Cheviot Sheep Society of Great Britain was founded in 1891. In America the American Cheviot Sheep Breeders organized in 1891. The National Cheviot Sheep Society was founded in 1894, there

having been some disagreement among the breeders of this country. In 1900 the two societies combined under the name of the American Cheviot Sheep Society and maintains an office at Fayetteville, N. Y. Up to January 1, 1914, they had registered 8,115 head. The following is the standard for judging Cheviot sheep:

	Points.
General conformation and quality: Deep and full breast and large through chest; back wide and straight, with well-sprung, deep ribs; legs well placed and leg of mutton full and thick; body well fleshed, skin pink, with no blue or dark coloring; fleece compact and medium fine; bone strong and fine; general appearance graceful, symmetrical, active.....	20
Size: In good flesh when fully matured a 24-months-old ram should weigh not less than 225 pounds and a ewe not less than 150 pounds.....	10
Head: Should be medium short and broad, with ample breadth between the eyes; ears should be of medium length and usually erect when at repose; head covered with clear white hairs, extending from nostrils to back of poll; ridge of head from between eyes to nostrils straight or slightly arched with females and more strongly arched or Roman with rams; color of tip of nose black.....	15
Body: Well proportioned, having notable depth, with thickness on top and at flanks. Loins should be very broad and thick; shoulders should set well back and be smoothly covered, and crops be full and well arched. The rump should be long, broad, and level.....	20
Legs: Should be short, well set apart, and be covered with clean, white hair, with no wool below hocks and knees. The hind legs should be flat and deep below hocks. Pasterns should be strong and not show weakness, supporting the body well.....	10
Feet: Symmetrical, squarely placed when in repose, and hoofs black in color...	5
Fleece: Should cover the body completely to behind the poll and ears and down to knees and hocks. Under part of the body should be well covered. In mature animals should be not less than 3 inches long for annual growth and be compact and of medium wool class. Rams should shear at least 12 pounds and ewes 8, when in mature form, to be desirable representatives of the breed.....	20
Total.....	100

Objections: Scurs on the head, black spots on the head, flesh-colored or spotted skin about the nostrils, hair about the thighs or kemp on the body, reddish or sandy hair on head or legs, lack of wool on under part of body.

Disqualifications: All male lambs shall be ineligible to registration if having scurs or horns exceeding 1 inch in length.

THE TUNIS.

The origin of the Tunis is lost in the mists of antiquity. Sheep have existed in an improved form in northern Africa for centuries, and the breed under discussion is said to have roamed the hills of Tunis and part of Algeria prior to the Christian era. They are sometimes called the "fat-tailed" sheep, but other breeds, perhaps not so well known, also possess this character

The first of these sheep to come to this country were those brought over by Gen. William Eaton, who was United States consul at Tunis. He received special permission from the Bey and shipped 10 head upon the man of war *Sophia*. Only one pair survived the voyage, and

these found a home upon the farm of Judge Richard Peters, of Belmont, near Philadelphia. This importation took place in 1799. About 1807 or 1808 Commodore Barron imported some into the District of Columbia, and in 1825, 13 head were landed at New York City.

Judge Peters bred these sheep for 20 years upon his farm, and they attained great popularity about Philadelphia for the quality of their mutton. It is said that the demand for lambs for eating purposes was so great that it actually hindered the development of the breed. However, flocks were eventually established in the South in the States of North and South Carolina, Virginia, and Georgia, where the breed also met with great favor, and increased in numbers until the Civil War, when they were almost entirely destroyed. In the North the sheep remained very popular until the fine-wool craze struck the country, during which time mutton qualities were entirely subordinated to wool. As the Tunis can not successfully compete with the Merino in the production of wool, it was eliminated from the race, and nothing more was heard of the breed until the Columbian Exposition in 1893. At this show a pen of Tunis sheep from South Carolina, descendants of those that had escaped destruction during the war, was exhibited, and a great deal of interest was manifested in the breed.

J. A. Guilliams, of Roachdale, Ind., purchased some of these sheep, and the next year he purchased 10 head of Col. M. R. Spigener, of Columbia, S. C., who had a flock of about 30 head, evidently the only one remaining in the South. Charles Rountree, of Yountsville, Ind., became interested in the breed about the same time, and his flock has since become famous. He has sold one lot, consisting of two rams and six ewes, to William Cooper & Nephews, who exported them to New Zealand. The American Tunis has been improved by an infusion of Southdown blood, and the fat tail of the original has been greatly reduced.

The fact that the Tunis has given such good results in the North and has survived through all the hardships with which it has met in the South speaks well for its adaptability and hardiness. But, while they have been popular in the North and have given excellent results, there can be little doubt as to their special adaptability to the Southern States. They are an especially hardy breed, largely able to take care of themselves, and the warm climate does not affect them adversely, as it does some other breeds. The ewes are very fertile and will mate at almost any season of the year. Because of their superior breeding qualities the ewes should be especially desirable for the production of early spring or hothouse lambs, and the South is a good field for this industry. Crossed upon other breeds the Tunis produces lambs of good mutton qualities, and they have thus wrought

marked improvement in the piney-woods sheep of the South wherever used. The largest number of purebred flocks are to be found in Indiana.

In Arizona, at the agricultural experiment station, Tunis bucks proved superior to those of other mutton breeds, notably the Oxford, Shropshire, Dorset, and Hampshire, for crossing upon the native ewes. They had excellent range qualities, were very prolific, and exhibited a tolerance to heat and a resistance toward the sheep bot fly unequaled by any of the other breeds. The rams were active, repelling the bot flies, and were more fertile than those of other breeds under the conditions mentioned. The cross resulted in larger and earlier lambs and a longer staple of wool, though not as fine as the native Merino ewe. The Tunis seems especially adapted to the climatic conditions of this region, which resulted in the mortality of a large number of the rams of other breeds, and bids fair to become quite popular in this State.

The Tunis is a rather small, rangy, early-maturing breed, rams weighing about 150 pounds in breeding condition. Ewes should weigh 120 pounds or better. The type of this breed is not very well fixed. Both sexes are hornless; the head is covered with short hair, tawny, yellow-brown, or brown and white in color. The ears are large and broad and pendulous.

In mutton qualities, the Tunis has a fair form, though mature sheep are somewhat patchy about the tail head, and the mutton is of good quality. The tail is characteristically broad and fat, it having been used for a storehouse where fat was stored in times of plenty to carry the animal over periods of famine. The fleece is of the medium wool type, compact and of fair quality, though it varies somewhat in color. A good fleece should weigh from 7 to 9 pounds. It usually grades quarter blood and three-eighths blood combing.

The breed has been criticized for being somewhat light in the leg of mutton and patchy about the tail head when mature.

The American Tunis Sheep Breeders' Association organized June 6, 1896, at Fincastle, Ind. The headquarters of the breed are at Crawfordsville, Ind. They have registered 2,530 head of sheep up to January 1, 1914. The following is the scale of points adopted by this association:

	Points.
Blood: Imported from Tunis, or a perfect line of ancestors extending back to the flock owned and bred by Judge Richard Peters, of Pennsylvania.....	20
Constitution: Healthful countenance; lively look; head erect; deep chest; ribs well arched; round body, with good length; strong, straight back; muscles fine and firm.....	15
Fleece: Medium length; medium quality; medium quantity; color white, sometimes tinged with gray; evenness throughout.....	10
Covering: Body and neck well covered with wool; legs bare or slightly covered; face free of wool and covered with fine hair.....	10

Points.

Form: Body straight, broad, and well proportioned; small bone; breast wide and prominent in front; tail should be docked short.....	12
Head: Small and hornless, or nearly so, tapering to end of nose; face and nose clean, brown and white in color; ears broad, pendulous, and covered with fine hair, brown to white in color.....	10
Neck: Medium in length, well placed on shoulders; small and tapering.....	5
Legs: Short; color, brown and white (wooled below the knee, not objectionable).	6
Size: In fair condition, when fully matured, rams should weigh 150 pounds and upward; ewes, 120 pounds and upward.....	6
General appearance: Good carriage; head well up, quick, elastic movements showing symmetry of form and uniformity of character throughout.....	6
Total.....	100

THE WELSH MOUNTAIN.

A number of different types are included under the name of Welsh Mountain sheep. Upon the highest hills of Wales the original sheep exists, but in other sections crosses have been made with the Leicester, Lincoln, Cheviot, Black-faced Highland, and Radnor forest breeds. The crosses with the Lincoln and Leicester have taken place mainly upon the fertile lowlands, and a larger earlier maturing sheep has resulted. This has been an advantage where the sheep are fed roots or other feed additional to their pasture, but where this is not practiced the cross has resulted disastrously because of the consequent lessening of the ability to rustle for itself.

The Black-faced Highland cross resulted in an increase in weight and amount of wool produced. The color of the wool was changed to yellow. The Cheviot cross produced similar characteristics, but resulted in a sheep too large for mountain grazing.

Upon the hilltops these sheep are very small, but upon the eastern slope of Berwyn and Merionith Hills they are larger and of a better type and possess much finer wool. It is said that a dark-faced type exists in Radnor, western Montgomeryshire, and parts of Merionith. The great difference in size and appearance may be accounted for by the different types of sheep used in crossing. They weigh from 32 pounds upward, and the mutton, with that of the Blackface and Southdown, is the best on the London market. The favorite type has a white face, though rusty brown, yellow, speckled, and gray faces may be found.

The poll is clean, but sometimes a tuft of wool is present upon the ram's head. The head is small, carried high, the neck is long, the shoulders somewhat low; the girth is small; and the sides are flat. The rams have gracefully curved horns, while the ewes are usually hornless. The wool of the better type is of excellent quality, the famous Welsh flannels, shawls, etc., being made from it. Fleeces are said to weigh from 2 pounds upward, depending upon the type.

The ewes usually drop but one lamb, but they are excellent mothers. The mountain flocks are usually brought down to the lowlands from November until April.

About 70 head of Welsh Mountain sheep have been imported to this country by the Beach estate, of Elmwood, Conn. These sheep were brought over in March, 1902. This is the only flock in the country at the present time. They seem to have given satisfaction to their owners, who report that the lamb crop averages about 130 per cent, that the average weight of fleece is $4\frac{1}{2}$ pounds, and that the mutton is of the choicest meat produced. Fair quality of wool grades quarter blood combing.

The Welsh Mountain Sheep Breeders' Association of Great Britain organized in 1905, and they published the first volume of their flock book the following year. There is no American association.

THE EXMOOR HORN SHEEP.

The Exmoor Horn is another old breed and have ranged the Exmoor and Brendon Hills for centuries. The Report of the Agriculture of Devon, 1808, describes them as being extraordinarily hardy and very active in searching for food. They were also said to have been narrow and flat sided in the early days, and some individuals were polled.

Youatt, 1837, says that the breed owes much to the cross with the new Leicester with respect to increased size, heavier fleece, and earlier maturity.

In 1844, the Exmoor Horn and the Dartmoor were reported as the principal mountain breeds of the West of England. The Exmoor was somewhat the smaller of the two, and the rams were distinctive in having a beard much resembling that of a goat. These sheep have been exhibited at the Royal, Bath and West of England, Somerset, and Devon County shows for a great many years. In a report of the Bath show in 1860 the breed was greatly admired for their symmetrical proportions, quality of flesh and wool, and for their adaptability to mountain districts. In Somerset and Devon Counties, the sheep are commonly raised upon the mountains and removed to the lowlands for fattening purposes.

In 1910, Wm. Cooper & Nephews imported a ram and three ewes of this breed for Frances Evans, Sugar Grove, Ill. The next year they imported eight yearling ewes and a ram for the same person. Other importations have followed.

The Exmoor is a small, white-faced, horned breed, noted for its activity and hardiness. The body presents a rotundity of form very pleasing to the eye. They much resemble the Southdowns, both in build and easy fattening qualities. They are, however, a trifle larger and carry a heavier fleece, especially upon the belly.

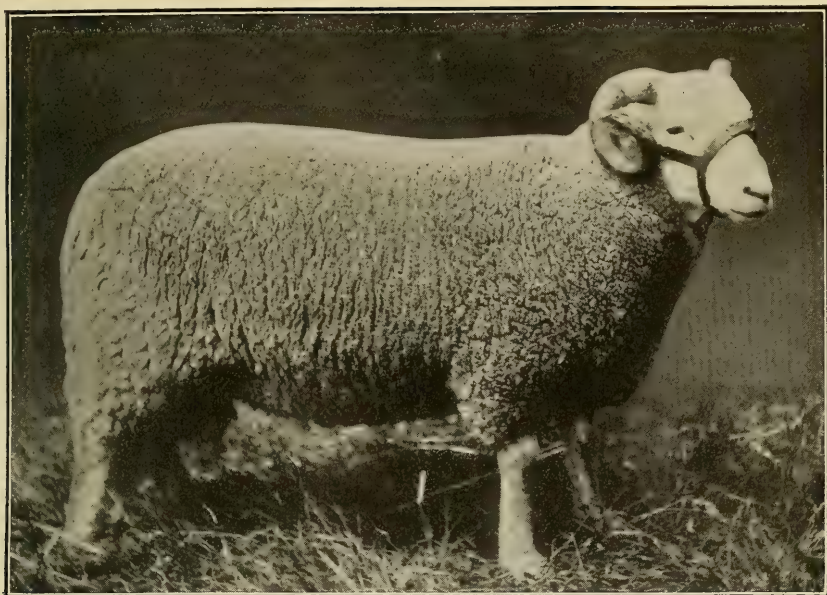


FIG. 1.—WELSH MOUNTAIN RAM.

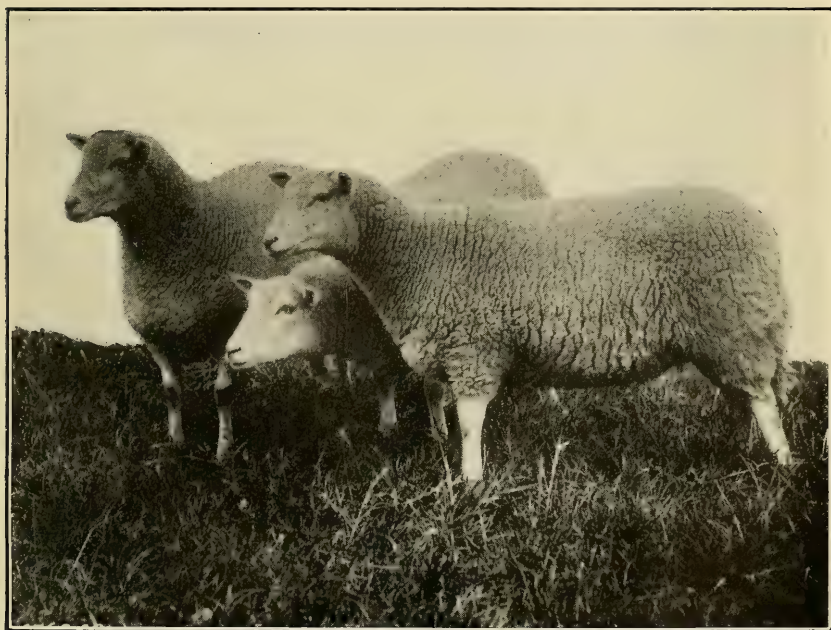


FIG. 2.—WELSH MOUNTAIN EWES.

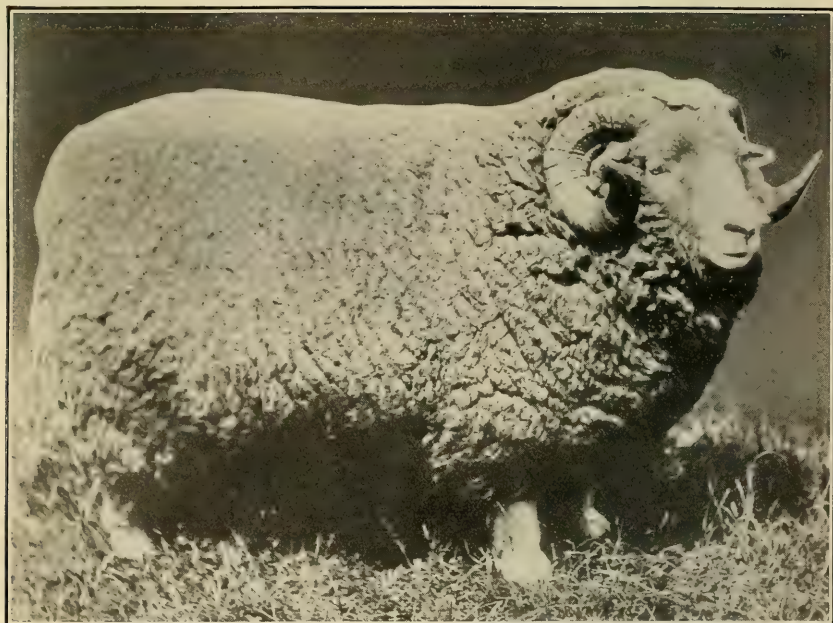


FIG. 1.—EXMOOR RAM.



FIG. 2.—EXMOOR EWES.

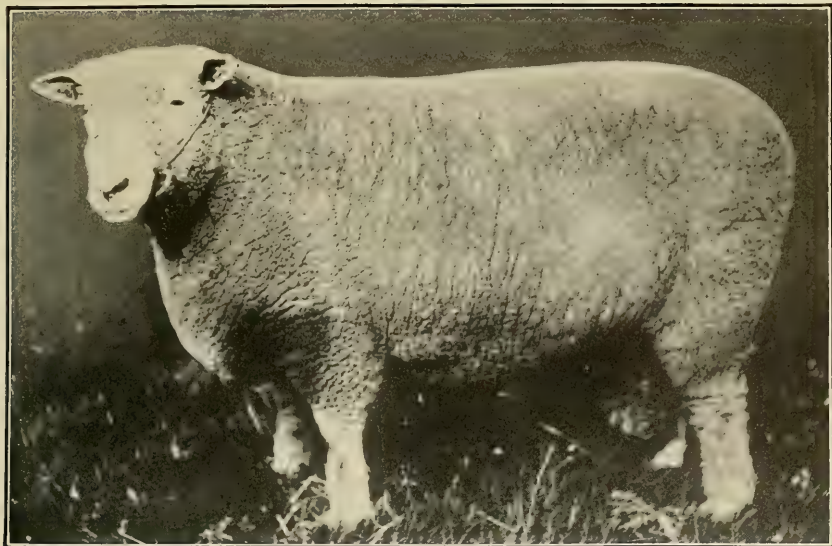


FIG. 1.—RYELAND RAM.



FIG. 2.—RYELAND EWE.



FIG. 1.—KERRY HILL RAM.



FIG. 2.—KERRY HILL EWES.

The wool is considerably longer and coarser than that of the Southdown. The mutton is of exceptional quality. The ewes are quite prolific and they are good mothers, though they are said to give less milk than the old type.

The importers speak very favorably of the breed and think that as soon as it becomes better known it will be popular in the hilly sections of this country.

The Exmoor Horn Sheep Breeders' Society of Great Britain was founded in 1906, and this society is doing considerable work in placing the breed before the public.

THE RYELAND.

The Ryeland derived its name from the tract of land in Herefordshire along the River Wye upon which rye had grown for a great many years. The breed was for a long time an important one, and it was especially prominent in the live-stock industry of the midland counties at the beginning of the last century, when it is said that Herefordshire alone pastured some 500,000 head of the breed, and there were also flocks in Monmouthshire, Gloucestershire, Shropshire, and Staffordshire.

The improved breeds, notably the Shropshire, crowded the old Ryeland out, and at one time it was thought that they were extinct. Much of the credit for preserving the breed is due to a Mr. Shepherd, of the district of Malvern.

The old Ryelands were a small, white-faced, polled breed, having considerable wool about the eyes. They were extremely hardy and capable of thriving upon scanty fare. The fleeces were of excellent quality, being finer than those of the Southdowns, but they rarely exceeded $2\frac{1}{2}$ pounds in weight.

Some authors held that the breed was of foreign origin, because of the practice of sheltering and feeding at night, which is unusual with other native sheep in this district. However this may be, a Merino cross was made when the latter sheep were introduced into England, but failure resulted from the experiment. Leicester blood is also said to have been introduced between the years 1800 and 1827, with accompanying length of fiber and increased size. For almost a century there has been no crossing, and the type is now fairly well fixed.

While the breed is again on the ascendancy, its distribution in England is by no means widespread. Wallace says that in 1903 there were about 30 flocks in existence, while in 1907 this number had increased to 200. They are to be found principally in Hereford and Brecknockshire, and in fewer numbers in Monmouth, Gloucester, and Worcester Counties.

Ryelands were first brought into the United States by George McKerrow, of Wisconsin, for the Colorado Experiment Station.

In the fall of 1907 one ram and three ewes were brought over, and three years later three more ewes were imported. They were crossed with Southdowns and Shropshires, the ewes proving remarkably good milkers and the lambs making rapid gains. They are exceptional mothers, being better than the more common mutton breeds in this respect. They are very fertile, producing many twins and triplets and have averaged a very high percentage of lambs; namely, 155 per cent. This percentage has been obtained from a very small number, hence it should not be overrated, as more extensive tests may not result as favorably.

The Southdown cross is said to have resulted in a very fine type of mutton sheep, being larger than the Southdown and possessing more spring of rib.

This breed is sometimes known as the White-faced Shropshire. The two breeds have considerable in common, and it is sometimes claimed that Ryeland blood entered into the development of the Shropshire. They are a hardy, compact breed, possessing great spring of rib. They thrive upon scanty pasture and fatten readily. They are claimed to be especially desirable for the production of early lambs, as the offspring are usually fat when dropped, but they have been criticized for this very property, as the carcass of a Ryeland, even under 1 year of age, is said to contain too great a percentage of tallow.

The head is a dull white color, covered with wool to the eyes and having a strip on either side of the face. The breed is characteristically strong at the juncture of the shoulders and neck. Mature rams in breeding condition should weigh from 200 to 225 pounds and ewes from 160 to 175 pounds.

The Ryeland breed is rather attractive and should find admirers in this country.

The fleece of the new Ryeland is considered heavier than that of the old prototype. The wool is of the combing class and resembles that of the Oxford Down, good fleeces weighing from 10 to 12 pounds. The quality is excellent, and this wool vies with that of the Dorset for premier place at the Royal. Upon the American markets it would usually grade as quarter and low quarter blood combing.

THE KERRY HILL.

The Kerry Hill is a Welsh breed of comparatively recent origin. Their home is in the Kerry Hills, which extend eastward and westward for 15 miles through the parish of Kerry, in Montgomeryshire. The region around about is famous for its improved live stock, as Shropshire sheep and Hereford cattle took form as breeds in neighboring shires.

The foundation breed was described in 1809 in the Agricultural Survey of Wales as the only breed that produced perfect wool, the

other Welsh breeds having more or less kemp. They had generally white heads; large, woolly cheeks; white, bunchy foreheads; were hornless; and had a beaver-like tail.

In 1840, Thomas Halford says the sheep were larger and heavier wooled than the pure Welsh sheep. The wool upon the body was fine, but lower down it was so coarse that it was always separated and sold at a lower price. Their faces and legs were often speckled with dark spots.

About this time rams were brought in from Knighton to use upon the flocks. These were of the Clun Forest breed with a very slight Shropshire cross. About 1855 the Kerry farmers ceased to use the foreign blood, as they could secure better rams by exchanging among themselves.

The breed now is undoubtedly a distinct one. The type is well fixed, and the sheep are quite uniform. It has been greatly improved by the use of root crops, as has many others, but it can no longer be spoken of as a mountain breed, in the sense that it is able to survive without artificial feeding. This breed was first recognized as distinct by the Royal Show at Lincoln in 1907.

Outside of Montgomeryshire, registered flocks can be found in Radnor, Hereford, Salop, Worcester, Durbright, and Cheshire. The ewes are also quite extensively used in crossing with rams of the Down breeds. The lambs produced are very popular for the fat-lamb trade. The annual fair and sale held at various places under the auspices of the breed association the last Friday in September is one of the best sheep shows in Britain. As many as 8,000 sheep have been exhibited at this fair. The breed is described as follows:

They are of medium size and have a rather dense covering of medium wool. They are broad of body, of considerable length, lacking slightly in depth, but are low to the ground. They are quiet and submit readily to folding. The mottled appearance of the face is very characteristic, and the mottles are very clearly defined.

In July, 1909, F. H. Neal, of Lucan, Ontario, Canada, imported three yearling ewes and a ram of the Kerry Hill breed. The experiment station of the University of Wyoming conducted some experiments with these sheep, and they reported the breed as being vigorous and hardy, but that they were light shearers and did not show evidences of superior merit from the mutton standpoint. Fleeces should weigh from 7 to 8 pounds and the wool grades quarter blood and low quarter blood combing.

The Kerry Hill Sheep Breeders' Association of Great Britain published their first flock book in 1894. This organization has done much toward placing the breed before the public. For a time the book was not published, but in 1899 it again appeared. There is no American association.

THE LONK.

To the Lonk belongs the distinction that its ancestors can not be traced from time immemorial. Youatt, Lowe, and the other old writers failed to mention it. Some claim to see in the Penistone sheep mentioned by Youatt the present Lonk breed, and indeed there seems to be some relationship, as the present Penistone breed has characteristics similar to those of the Lonk.

About 50 years ago "The Druid," a famous writer upon live-stock subjects in Great Britain, wrote an account of this breed, which seems to be the oldest in existence.

The name Lonk is said to be derived from the coarse herbage growing upon the moorlands of North Lancashire, West Riding, of Yorkshire, and part of Derbyshire, of which places this breed is native. It is also claimed that the term is a corruption of Lancashire. The district about Clitheroe and Skipton is one of the breed's special strongholds.

The Lonk is a large mountain breed, somewhat resembling the Black-faced Highland. It is heavier, longer, more upstanding, and has a larger head. The fleece is shorter, denser, finer, and somewhat heavier than that of the Black-face.

The face and legs are black and white, the spots being very distinct. Brown is objectionable. There should be no wool upon the face and legs, but a small tuft upon the forehead and a fringe upon the hind legs. However, the wool comes up close behind the horns, which are to be found in both sexes. Fleeces are reported from 4½ to 11 pounds in weight. The wool grades quarter and low quarter blood combing in America.

This breed is said to be not as hardy as the Black-face, and when used in crossing upon the latter decreased constitution resulted.

Wm. Cooper & Nephews imported in 1908, for the Bitter Root Ranch, at Hamilton, Mont., 50 ewes and 5 rams of this breed. In 1911 three more rams were imported for the same company. These sheep are said to have done fairly well, but they are unsuited to range conditions, as it is impossible to herd them. The above-mentioned company disposed of their stock for this reason.

The Lonk Sheep Breeders' Association and Flock Book Society of England issued the first volume of their flock book in 1905. They claim for the breed that it is especially adapted to mountainous districts. There is no American association.

THE SHETLAND.

This breed, if it may be called one, comes from the Shetland Islands, which are located northeast of Scotland. It is said that the pure Shetland exists only upon the islands of Foula and Papa Stour. They are a very small breed, weighing from 30 to 40 pounds when



FIG. 1.—LUNK RAM.

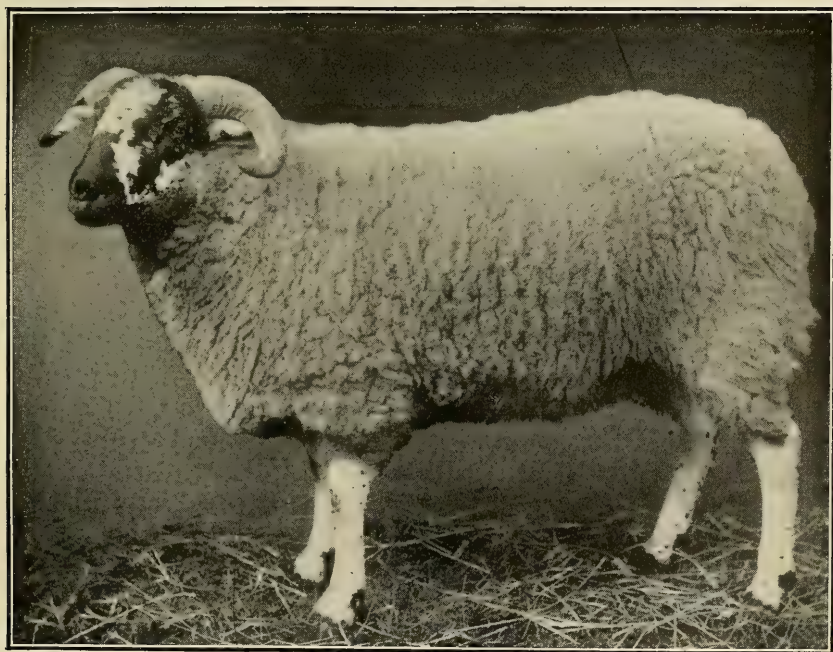
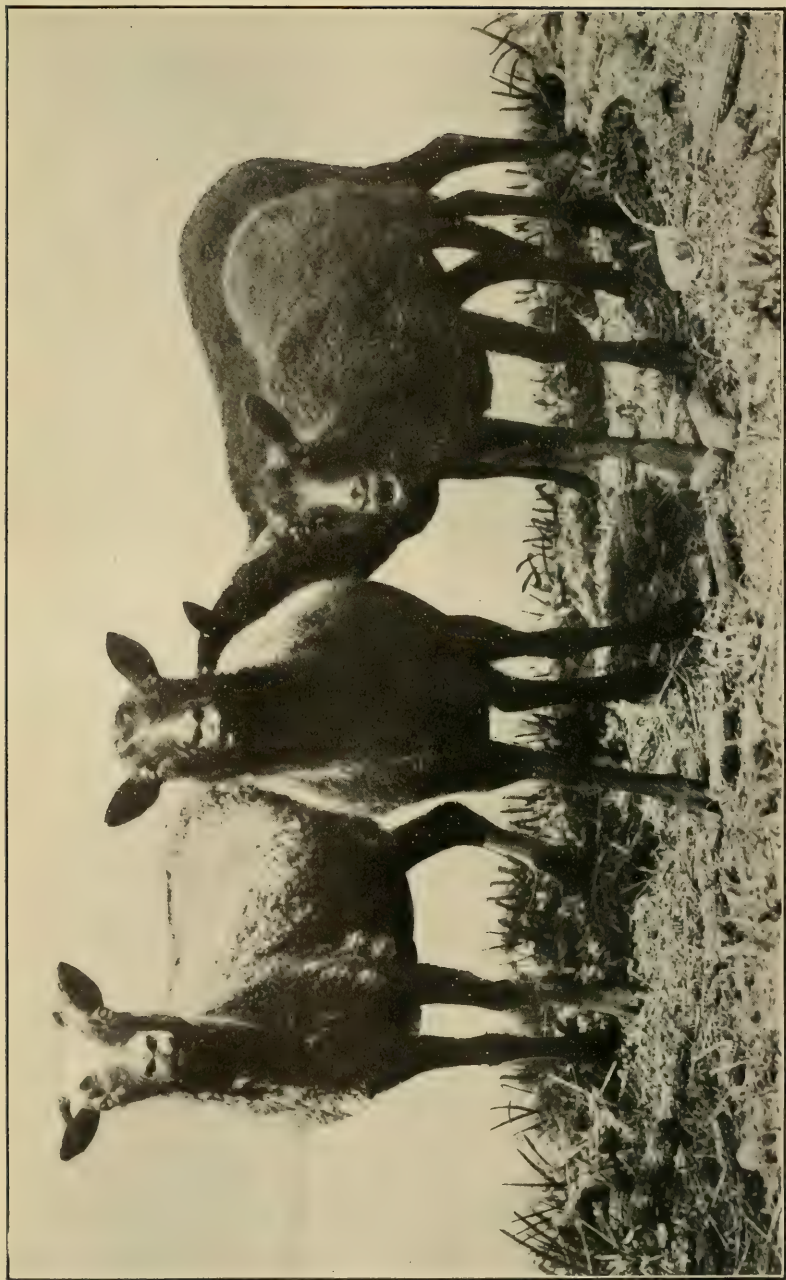


FIG. 2.—LUNK EWE.



SHETLAND EWES.

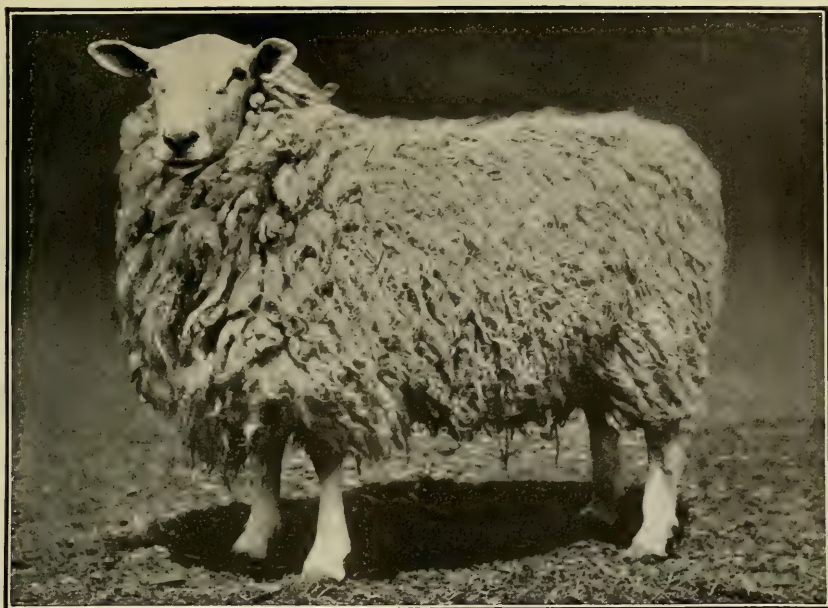


FIG. 1.—LEICESTER RAM.



FIG. 2.—LEICESTER EWE.



FIG. 1.—COTSWOLD RAM.



FIG. 2.—COTSWOLD EWE.

mature, and they are noted for their excellence of mutton and fineness of wool. They are also very hardy, especially those that have access to the seaweed. It is a strange thing that these sheep know when the tide recedes even though they may be several miles inland. There is an old legend that is still credited to a certain extent upon these islands to the effect that there is a worm in the sheep's foot that turns as the tide recedes.

Not all individuals have horns, but this type is preferred. The tail is short and pointed at the end. In color they may be black, white, brown, or almost any combination of these. The average weight of fleece is about 2½ pounds. The sheep are never shorn, but in the spring the wool loosens from natural causes and rises up through the coat of hair that also covers the animal. The sheep are driven into "crues," or "punds," as they are called, about once a week, from May 15 to the last of June, and "plucked." There may be more than a week's difference in the loosening of the wool on the sides from that on the back. The plucking process causes no pain and is much superior to shearing in the case of these sheep. The latter process would remove the hair which acts as a protection to the animal and which would be objectionable in the wool. Shearing would also result in the cutting of the new wool, another undesirable feature.

The fleeces of these sheep are used in the manufacture of hosiery and for the famous Shetland shawls.

A great deal of crossing, involving Black-faced Highland, Leicester, and Cheviot blood, has taken place upon the islands, and there is danger of the breed being crossed out of existence.

Wm. Cooper & Nephews made an importation of 17 head of Shetlands for W. W. Burch, of Michigan. R. S. Blastock, while purchasing sheep in England in 1910 for Mr. L. V. Harkness, of Kentucky, was presented with three ewes and a ram. These were taken to the Walnut Hall estate at Donerail, and they are slowly increasing in numbers.

The specimens brought to this country were largely black and brown, with occasional white markings. They are deer-like in appearance and are very timid, it being very difficult to closely approach them. They make a beautiful sight in a park and are suitable only for such purposes in America. They have fittingly been called a "toy" sheep.

THE LEICESTER.

Even though the English Leicester does not exist in the United States in the pure form, any treatise upon the breeds of sheep would be incomplete without reference to this one. They were one of the first of the modern improved breeds of live stock, and the influence the Leicester has had in developing the other breeds is almost incom-

prehensible. Their improvement is noteworthy, not only because they were later able to directly impart their superiorities to other breeds, but also because principles were established in their development that have since been of inestimable value in establishing and improving other breeds.

To Robert Bakewell, of Dishley Hall, near Loughborough, Leicestershire, belongs the honor of establishing this breed, and he has fittingly been called the "father" of improved live stock. Bakewell was a rather quiet man, and there are stories about a "black ram" that he used in his breeding operations and of other secretive proceedings that he resorted to. It is much more likely that he used the long-wool sheep of his district, and especially the Old Leicesters, which have been described as being a long, thin, flat-sided, slow-maturing sheep possessing large bones and rough legs and generally lacking in quality. Their fleece was from 12 to 15 inches long and heavy, and this had been the chief consideration in their development. Bakewell began breeding in 1755 for improved form, better feeding qualities, earlier maturity, and reduction of bone and offal. In other words, he bred for more mutton and paid little or no attention to wool. He bred the "best to the best," to use his own expression, and practiced inbreeding whenever he deemed it necessary. He was an exceptional judge of live stock, and he constantly mated animals together of his approved type until he had succeeded in establishing a breed that would almost invariably hand down their characteristics to their offspring. To be brief, he fixed the type.

However, with the improvements there were also some weaknesses that manifested themselves in the New Leicester. These were more delicacy of constitution, impaired milking qualities, a lighter fleece, and decreased prolificacy. At this time, however, these were not regarded as of very great importance.

For a time Bakewell had trouble in convincing the public of the desirability of his breeding stock, but later these sheep became very popular and spread all over England. The Dishley Society was founded about 1790 for advancing the interests of the breed, and it greatly aided in further establishing the Leicester. This society preferred to rent their rams. After they were established the Leicester became very popular for crossing upon the other breeds, as they were prepotent to such an extent that the cross usually possessed most of the good qualities of the breed.

The mutton was never of the highest quality. It was coarse-grained and contained too much fat, which was deposited externally instead of being mixed with the lean. As the demand at that time was for quantity rather than quality, this had little effect upon the popularity and distribution of the breed. Since then the importance

of quality has been emphasized, and to-day the purebred Leicester is no longer common in England. Flocks are still to be found, however, in East and North Yorkshire, Cheshire, Cumberland, Durham, and Leicestershire. Because of their value in crossing and the important part that they have played in establishing the ovine breeds, it is to be hoped that they will not be entirely lost in crossing upon other breeds.

The Border Leicester is sometimes considered a type of the English or New Leicester, but there are differences enough to justify it being classed as a distinct breed, and this has been done in Britain. The origin of this breed is debatable. In 1767 George and Matthew Culley, friends of Bakewell, established themselves upon a farm at Fenton, near Wooller, among the Cheviot Hills. They took some of Bakewell's improved stock with them, and some authorities claim that this was crossed upon the Teeswater sheep in the establishment of the new breed, while others claim that the Cheviot entered as a foundation stock. At any rate, the breed is now established in Northumberland, Yorkshire, Durham, and Lothian.

The principal differences between the Border and Bakewell types are as follows: The head of the former is clean cut, covered with short white hair, and entirely free from wool. The face is white and the ears are carried erect. The features of the latter are not so sharply defined; they are slightly woolled about the top of the head, and the wool carries down farther upon their legs. Their face has a bluish tinge, and they are not so neat about the middle as the Border type.

The improved mutton qualities of the Border Leicester have greatly aided it in replacing the older type. Its adaptability to conditions in northern England and southern Scotland have caused it to be called the "mainstay of farming" in the border counties. The rams are very popular here for crossing upon Cheviot ewes.

Bakewell, or Dishley, Leicesters were introduced into America before the Revolutionary War. Records show that Washington used rams of this breed in improving his flock at Mount Vernon, which at one time amounted to 800 head. Purebred Bakewell ewes were also brought over, for when Washington's flock was dispersed in 1802 George Washington Custis purchased three of these animals. The Arlington Longwools, famous in early American sheep history, were developed by the latter gentleman, who followed Washington's plan of breeding the "Persian" sheep of the neighborhood to improve Leicester rams. The Arlington flock made steady progress until eclipsed by the Merino. After the advent of the latter they were no longer bred pure to any considerable extent. Some of the sheep of the South, especially the Tennessee mountain variety, resemble these, and it is not improbable that they have descended from them.

The date of the first importations of Border Leicesters is unknown, both types of the breed having been registered by the same association, and no mention was generally made of the type imported. During recent years importations have been very rare. Practically all of the Leicesters in America to-day are of a modified border type. This modified American type is considered by many sheepmen to be superior to either the English or Border Leicester.

The breed is much more popular in Canada, and especially in Ontario, than in the United States. Michigan, New York, Pennsylvania, and Vermont have the largest number of registered flocks. At least one prominent sheepman of the West is securing good results by crossing Leicester rams upon range ewes.

The Leicester is the smallest of the long-wool breeds. Rams usually weigh from 225 to 275 pounds and ewes from 175 to 225 pounds. The body is neat, showing great spring of rib, causing apparent lack of depth; the mutton is not of especially high quality. The fleece is of good length, the ringlets are more pronounced than in any other breed, and the fiber is of good quality. Ten to twelve pounds is a good average clip for a flock, and the wool usually grades braid and quarter blood combing. The fecundity and early maturing qualities of the Leicester are only fair. None of the long wools are decidedly superior in these respects. The Leicester is one of the few breeds of sheep that is acknowledged to have been improved in America, but the mutton qualities could still be considerably improved. The carcass is too large when mature and the quality is not what might be desired. They are also more upstanding than is desirable.

The Dishley Society for the promotion of the Bakewell Leicester was one of the first organizations founded for the purpose of promoting a breed. Its existence has been charged as due entirely to selfish motives, but whether or not this was the case, it aided in establishing these sheep.

At the present time in England there are separate societies for registering and promoting the Border and English types, but in America one organization has registered both. It is known as the American Leicester Breeders' Association and was established in 1888. Up to January 1, 1914, 15,913 sheep have been registered. The secretary of the association is located at Cameron, Ill. There is no scale of points, and none could readily be devised covering both types.

THE COTSWOLD.

For several centuries certain sheep of Gloucestershire and parts of Hereford and Worcester have borne the name of Cotswolds. Some authors claim that they derived their name from the region and others claim that the hills derived their name from the sheep. The derivation of the word is from "cote," a sheep shelter,

and "wold," a stretch of upland. It seems that in the early days the Cotswold was a fine-wooled breed, greatly famed for the quality of the wool. Later the sheep that bore the name were a large, coarse-wool breed, of great vigor and constitution. These latter sheep were undoubtedly the stock from which the present Cotswold breed has been developed, but whether the fine-wooled sheep spoken of were more remote ancestors is a question that has not been satisfactorily answered. There are stories that the sheep of this region furnished wool for the Romans 2,000 years ago, but there is probably no more similarity between the modern Cotswolds and these sheep than between the other modern breeds and the ancient types from which they sprung.

The improvement of the Cotswolds began about 1780 by the introduction of Leicester blood, and from this time up until 1820 few, if any, flocks escaped an infusion of Bakewell blood. This new blood reduced the size and constitution of the original Cotswolds, but it improved them in form and quality and introduced earlier maturing characteristics. For the last 75 years the Cotswold breed has been kept comparatively pure, but the breed was not awarded a distinct class at the Royal Show until the Battersea meeting of 1862. The Smith family, of Bilbury, and the Hewers, of North Leach, were prominent early breeders of Cotswolds.

In Great Britain the Cotswold is not common outside of its native district. In foreign countries it has found favorable environs, especially in parts of Canada and the United States. Cotswolds have also been exported to Australia, New Zealand, France, Germany, and Russia.

Mr. Christopher Dun, of Albany, N. Y., made an importation of Cotswolds in 1832. Other importations followed, large numbers of these sheep being brought over during the next half century. Fewer importations have been made during the last 25 years.

Purebred Cotswolds have been registered from almost every State in the Union. Formerly there were a good many flocks in the East, but the breed does not do especially well in this section and they have been largely replaced by other breeds. In the Middle West, Wisconsin has some notable flocks, and this State is one of the strongholds of the breed. In the far West, Oregon and Utah are famous for their excellent flocks. In the Willamette Valley in the former State, Cotswolds are produced that equal in excellence those of the native hills of England. This is the breeding ground for large numbers of rams that are used for crossing upon the Merino ewes of the range, especially in Montana and Idaho. The half-blood sheep are considerably larger than the Merino, and they produce a longer fleece. It is largely the range demand that has caused the breed to become so popular in America.

With the exception of the Lincoln the Cotswold is the largest breed of domesticated sheep. Rams weigh from 300 to 350 pounds and ewes from 200 to 250 pounds. They have white, light-gray, or spotted faces, have a large foretop, and they carry their heads very erect. Their mutton is of fair quality, though the admixture of fat and lean is not as good as in the Down breeds. The feeding qualities are very good, and they give good gains for the amount of feed consumed, but if denied feed or care they become very unsightly. The fleece is somewhat open, the wool is in ringlets of good length and quality. Fleeces should average about 12 pounds of braid or low quarter blood combing wool. In fecundity and early maturing qualities the Cotswolds are about medium.

The fleece of this breed is more open than is desired and there is a tendency for the poorer individuals to be ewe necked and low in the rump. The quality of the mutton could also be improved. Another criticism is that under unfavorable conditions the Cotswold becomes very unsightly.

The Cotswold Sheep Society of England was organized in 1892. The American Cotswold Sheep Society was organized at Chicago in 1878. Up to January 1, 1914, they have registered 74,455 sheep, but one other American association having surpassed them in the number of sheep on record. The headquarters of the association are at Waukesha, Wis. The following is the standard of excellence and scale of points for Cotswold rams and ewes:

FOR COTSWOLD RAM.

	Points.
Head not too fine, moderately small and broad between the eyes and nostrils, but without a short, thick appearance, and in young animals well covered on the crown with long, lustrous wool.....	8
Face either white or slightly mixed with gray, or white dappled with brown.....	4
Nostrils wide and expanded; nose dark.....	1
Eyes prominent, but mild looking.....	2
Ears broad, long, moderately thin, and covered with short hair.....	4
Collar full from breast and shoulders, tapering gradually all the way to where the neck and head join. The neck should be short, thick, and strong, indicating constitutional vigor, and free from coarse and loose skin.....	6
Shoulders broad and full, and at the same time join so gradually to the collar forward and chine backward as not to leave the least hollow in either place.....	8
Fore legs: The mutton on the arm or fore thigh should come quite to the knee. Leg upright, with heavy bone, being clear from superfluous skin, with wool to fetlock, and may be mixed with gray.....	4
Breast broad and well forward, keeping the legs wide apart; girth or chest full and deep.....	10
Fore flank quite full, not showing hollow behind the shoulders.....	5
Back and loin broad, flat, and straight, from which the ribs must spring with a fine circular arch.....	12
Belly straight on underline.....	3
Quarters long and full, with mutton quite down to the hock.....	8
Hock should stand neither in nor out.....	2

Points.

Twist or junction inside the thighs, deep, wide, and full, which, with a broad breast, will keep the legs open and upright.....	5
Fleece: The whole body should be covered with long lustrous wool.....	18
Total.....	100

FOR COTSWOLD EWE.

Head moderately fine, broad between the eyes and nostrils, but without a short, thick appearance, and well covered on crown with long, lustrous wool.....	8
Face either white or slightly mixed with gray, or white dappled with brown....	4
Nostrils wide and expanded; nose dark.....	1
Eyes prominent but mild looking.....	2
Ears broad, long, moderately thin, and covered with short hair.....	4
Collar full from breast and shoulders, tapering gradually all the way to where the neck and head join; the neck should be fine and graceful, and free from coarse and loose skin.....	5
Shoulders broad and full, and at the same time join so gradually to the collar forward and chine backward as not to leave the least hollow in either place.....	8
Fore legs: The mutton on the arm or fore thigh should come quite to the knee; leg upright with heavy bone, being clear from superfluous skin with wool to fetlock, and may be mixed with gray.....	4
Breast broad and well forward, keeping the legs wide apart; girth or chest full and deep.....	10
Fore flank quite full, not showing hollow behind the shoulder.....	4
Back and loin broad, flat, and straight, from which the ribs must spring with a fine circular arch.....	12
Belly straight on underline.....	5
Quarters long and full, with mutton quite down to the hock.....	8
Hock should stand neither in nor out.....	2
Twist or junction inside, the thighs deep, wide, and full, which, with a broad breast, will keep the legs open and upright.....	5
Fleece: The whole body should be covered with long, lustrous wool.....	18
Total.....	100

THE LINCOLN.

The Old Lincolns were mentioned as an established breed as early as 1749. The modern type of this breed resulted from crossing Leicester rams upon the Old Lincoln ewes. The breed was recognized by the Royal Agricultural Society as distinct in 1862. Their home is in Lincolnshire, in northeastern England, the east side of the county touching the sea.

The Old Lincolns were the largest breed of sheep in Britain. They were coarse and had white faces and legs and heavy heads and necks. They lacked spring of ribs and were low in the back. They produced a very heavy, oily fleece, though their bellies and legs were said to have been almost bare. They were slow at reaching maturity and did not feed very well. The Leicester blood improved the symmetry and feeding qualities very greatly; it also induced early maturity. The Dudding family, of Riby Grove, Great Grimbsy, Lincolnshire,

bred Lincolns for about 175 years. This famous flock was dispersed in July, 1913.

Until about 1850 little attention was given the Lincoln outside of its own locality. Since that time it has spread over Lincolnshire, Rutland, and several neighboring counties. The breed has also become famous in Australia, New Zealand, South America, South Africa, Canada, and the United States. Crossed upon fine-wool sheep of Merino blood, the Lincoln has given especially favorable results in Australia, New Zealand, and South America. The large body and long fleece are apparent to such an extent in the cross that a very profitable lamb results. By continuing this crossing the Corriedale breed has been established in the former countries. The Lincoln is also bred pure in these countries, but the type is somewhat different from the English Lincoln.

Old-type Lincolns are said to have been brought to America previous to 1796. In 1825 A. A. Lawrence, of Massachusetts, made an importation of 10 head of the improved type, and several other importations followed shortly afterwards. A Lincoln ram was recently imported to Oregon from New Zealand. The type varied considerably from that of the English breed.

The Lincoln is adapted to fairly fertile and arable farming sections, as they do not thrive upon broken pasture. They also require a fairly humid climate for their greatest development, which accounts for their importance in Oregon. In this State they attain a measure of excellence not excelled by those of England. The Willamette Valley is the breeding grounds for Lincoln rams for use upon the range, and the demand is greater than the supply. Ohio and Michigan are also noted for their purebred flocks. In Oregon and Montana especially, and in some of the other States to a lesser extent, a great many cross-bred Lincoln fine-wool lambs are produced. The lambs produced by this cross are exceptionally profitable and are very popular upon the market.

Taken as a breed, the Lincoln is the largest of all English sheep, but individuals of the Cotswold breed may equal them in size. The rams should weigh from 250 to 375 pounds and the ewes from 225 to 275 pounds. Their mutton is only of fair quality, it being somewhat coarse and not as palatable as that of the Down breeds.

As the Lincoln is the heaviest breed, it also produces the heaviest fleece of all the mutton breeds. The staple is long (samples being reported that measured 21 inches), very lustrous, and hangs together in distinct staples. Fleeces have been reported that weighed 32 pounds washed wool, but they usually range from 12 to 16 pounds, with 14 pounds as a good average for a flock. The commercial grades of this wool are braid and low quarter blood. In the Northwest fleeces are sometimes allowed to grow for longer periods than one year,

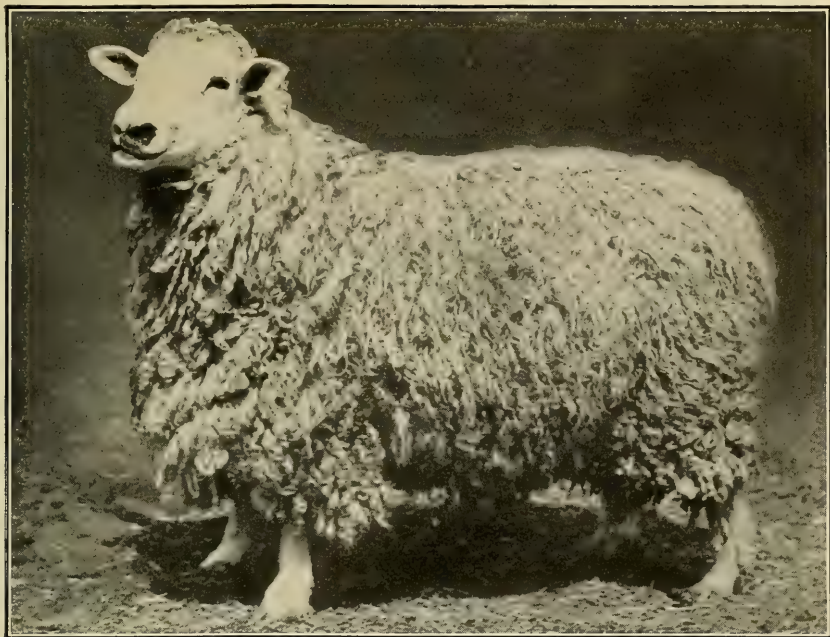


FIG. 1.—LINCOLN RAM.

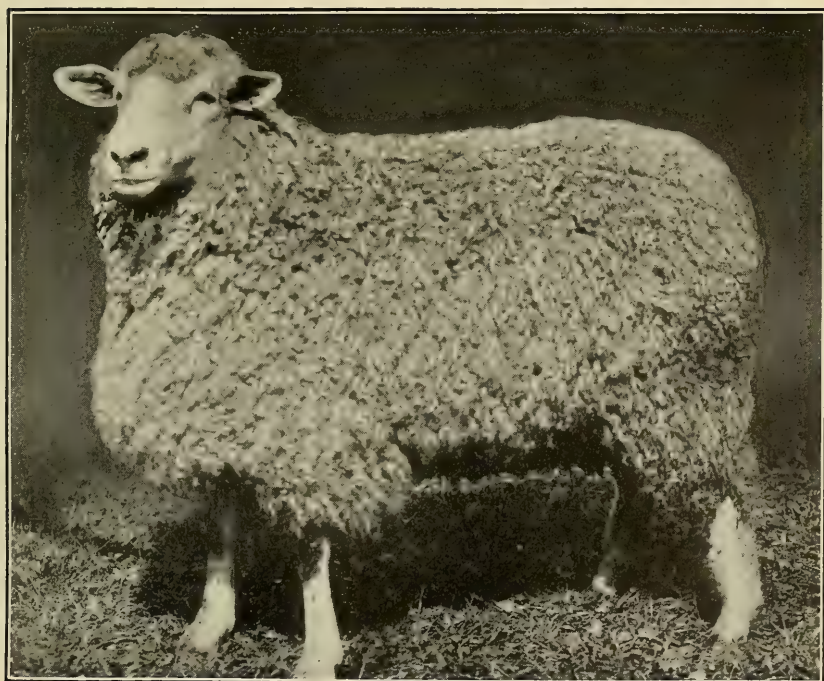


FIG. 2.—LINCOLN EWE.



FIG. 1.—ROMNEY MARSH RAM.



FIG. 2.—ROMNEY MARSH EWE.

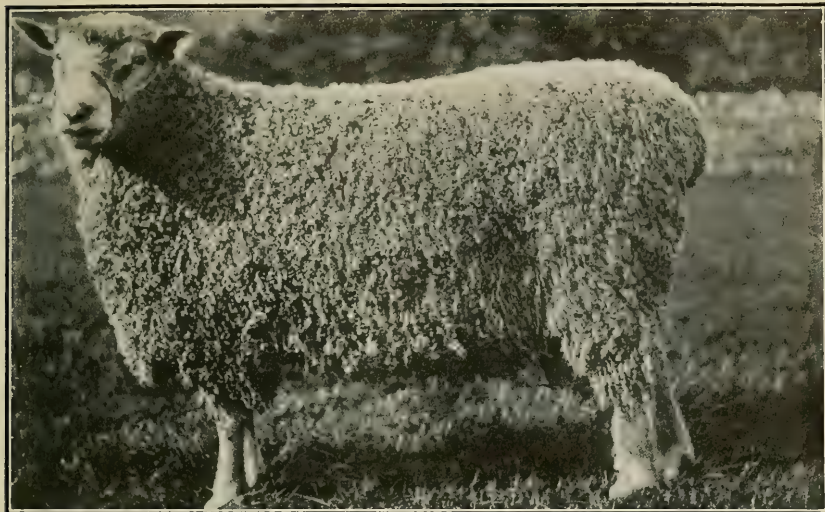


FIG. 1.—WENSLEYDALE RAM.



FIG. 2.—TRIO OF WENSLEYDALE EWES.



FIG. 1.—DARTMOOR RAM.



FIG. 2.—DARTMOOR EWE.

extra long staple being produced that sells for as much as \$1 a pound. However, the amount of this trade is limited.

In early maturity and fecundity the Lincoln is similar to the other long-wool breeds. None of them have these qualities developed as strongly as the Down breeds. The ewes give a fair amount of milk.

The Lincoln Longwool Sheep Breeders' Association of England was organized in 1892. The National American Lincoln Sheep Breeders' Association was founded at Lansing, Mich., in 1891. They have registered up to January 1, 1914, 26,122 head, and the secretary is now located at Charlotte, Mich. The following standard and scale of points has been adopted:

STANDARD AND SCALE OF POINTS OF LINCOLN SHEEP.

	Points.
Constitution: Body deep, back wide and straight; wide and full in the thigh; bright, large eyes; skin soft and of a pink color.....	25
Size: Matured rams not less than 250 pounds when in good condition; matured ewes not less than 200 pounds.....	10
Appearance: Good carriage and symmetry of form.....	10
Body: Well proportioned, good bone and length; broad hind quarters; legs standing well apart; breast wide and deep.....	15
Head: Should be covered with wool to the ears; tuft on forehead; eyes expressive; ears fair length; dotted or mottled in color.....	10
Neck: Medium length; good muscle; well set on body.....	5
Legs: Broad and set well apart; good shape; color white, but some black spots do not disqualify; woolled to the knees.....	10
Fleece: Of even length and quality over body; not less than 8 inches long for 1 year's growth.....	10
Quality of wool: Rather fine, long wool; strong, lustrous fiber; no tendency to cot.	5
Total.....	100

THE KENT, OR ROMNEY MARSH.

The Romney Marsh sheep originated in the low-lying tract of land bearing the same name in the county of Kent, in southeastern England. The marsh is about 14 miles long and 10 miles broad. It is a low, level, alluvial plain, and high tide at one time covered it, but since then the sea has been held back by embankments. The exact age of the old-type Romney is unknown, but it is supposed that they roamed the marsh for at least several centuries.

Like all other ancient breeds, the prototype of the modern Romney lacked mutton form, symmetry, and quality. They were, however, very hardy and produced a heavy fleece of long wool. They were good grazers and rarely received any feed other than pasture throughout the year.

The infusion of Leicester blood, that probably took place, as in all the longwool breeds, was not very successful in the Romneys, especially where the proportion of the foreign blood was at all large. While it improved the form, the quality, and the early-maturing

characteristics, it also reduced the size, the weight of fleece, the constitution, and their ability to rustle for themselves. This being the case, the breeders later used the Leicester for a type and approached its desirable qualities as nearly as possible through selection within the breed itself.

The Romneys are still the favorite sheep in their native marsh. They subsist here without artificial feeding throughout their second winter. From this native habitat they have gradually spread over the county of Kent, and flocks are also to be found in Sussex, Herts, and Rutlandshire.

They have been exported in increasing numbers since the establishment of the English breed association in 1895, and are especially popular in New Zealand and Argentina.

F. W. Harding imported for William Riddell & Sons in 1904 four ewes and one ram of this breed from England. They were exhibited at the St. Louis Exposition, but did not make a very favorable impression. Eleven ewes and one ram were imported in 1909 for the same firm from New Zealand. Those from New Zealand were smaller, had more quality, and were better shearers than the English. The same year Mr. A. T. Hickman, of Egerton, Kent, exported 32 head of rams to America, which were sold during the International Live Stock Exposition of that year. They realized an average of only \$24.125 per head, a rather low price when \$1,500 has been realized for a single ram in England.

As to adaptability of this breed to this country, much is yet to be determined. Where they have been crossed upon fine wools they have given large, strong lambs, and the promoters are high in their praise of this breed. It is claimed that Romney lambs are larger at birth than those of any other sheep. It seems altogether probable that the breed will take a prominent place among the other long wools of this country and enrich our live-stock industry by so doing.

Three ewes and one ram were also imported for the Wyoming Experiment Station in the fall of 1906, and they seem to have made a favorable impression, both the purebreds and the crosses that have been produced.

The breed is white-faced and hornless and unusually hardy. Rams should weigh from 200 to 225 pounds and ewes from 175 to 200 pounds. The mutton is the best of the long-wool breeds, ranking next to the Downs, and it enters prominently into the frozen-carcaass trade of New Zealand and Argentina. The fleece is long and dense and has some of the characteristics of the medium wools, the ringlets characteristic of long wools being not as much in evidence. The foretop may be either present or absent. Fleeces should weigh from 12 to 16 pounds. The wool ordinarily grades a low quarter blood combing.

The fecundity of the breed is ordinary, a lamb to a ewe being considered a good average.

The breed is criticized in England for lacking fixity of type and for being prominent in the backbone and shoulders. Hardly enough specimens have come to this country to enable one to criticize them justly.

The Kent, or Romney Marsh, Sheep Breeders' Association of England was founded in 1895, and it has done much to advance the interests of the breed. The New Zealand Romney Marsh Sheep Breeders' Association was organized about the same time. The Romney Sheep Breeders' Association of America was organized December 5, 1911, at Chicago. Up to January 1, 1914, they have registered 124 head of sheep. The association has been very active in advancing the breed in every possible way, and a number of other importations have resulted from their endeavors. The offices are at Mechanicsburg, Ohio.

THE WENSLEYDALE.

The Wensleydale is the modern form of the old Teeswater breed. In some parts of their native country, notably North Lancashire, they are still known by the latter name. They were also locally known by the name of "Mugs" until 1876, since which time they have borne their present name. It is said that these sheep were used by Bakewell in developing the Leicester, and there is considerable similarity between the two breeds. However, this likeness may be due to the Leicester blood that was subsequently introduced into the Wensleydale. Mr. R. Outwaite, of Appleton, the "Patriarch of the Wensleydales," used a large Leicester ram, a son of which was the sire of the famous ram "Blue Cap," shown at the Liverpool Royal in 1841. Mr. Outwaite refused 100 guineas for this famous sire. To him and to his sons can be traced most of the leading characteristics of the modern Wensleydale. The Leicester rams imparted early maturity, smaller, more compact carcasses, better quality of mutton, and a finer, denser fleece to the old breed. The present location of the breed is in north and northwest Yorkshire, Cumberland, and Westmoreland Counties.

In July, 1906, F. H. Neal, of Lucan, Ontario, Canada, imported three yearling ewes and one ram of the Wensleydale breed for the Wyoming Experiment Station. These did not prove popular, being too leggy and having open fleeces, and when crossed upon other breeds did not give flattering results. It is possible that the poor showing made was due to the fact that those imported were not good specimens.

The Wensleydale is a large, high-standing, hornless, long-wool breed, very active and hardy. The face and legs, and the entire skin to a less degree, are blue. This color is preferable because dark-faced lambs are desired when this breed is crossed upon the Black-faced Highland. These lambs are known as "crosses," or "Mashams," in Britain. The mutton is of good quality, the fleece is long and open, the locks falling in close ringlets, and the fiber is of good quality. They are said to be quite fertile and to make good mothers.

In England there are rival breed associations. Both of these associations were founded about 1890. One was known as the Pure Select Wensleydale Sheep Breeders' Association, but changed its name later to the Incorporated Wensleydale Sheep Breeders' Association. This society holds its annual fair at Hillifield. The other is called the Wensleydale Longwool Sheep Breeders' Association, and this society's fair is held at Northallerton. The scale of points of the latter English Society will be given, as there is no American society.

SCALE OF POINTS FOR WENSLEYDALE RAMS.

	Points.
Head: Face dark; ears dark and well set on; head broad and flat between ears; muzzle strong in rams; a tuft of wool on forehead; eyes bright and full; head gaily carried.....	15
Neck: Moderate length, strong, and well set on to the shoulders.....	10
Shoulder: Broad and oblique.....	5
Chest: Deep and wide.....	10
Wool: Bright luster; curled all over body; all alike in staple.....	20
Back and loins: Ribs well sprung and deep; loins broad and covered with meat; tail broad; flank full.....	25
Legs and feet: Straight and a little fine wool below the hock; fore legs well set apart; hind legs well filled with mutton.....	15
Total.....	100

THE DARTMOOR.

On either side of the Dartmoor in Devonshire a type of sheep has developed that is designated as the Dartmoor breed. Some claim that the foundation stock of this breed was the same as that of the Exmoor, and this theory is as plausible as any, but for at least three generations the breed has been distinct from the Exmoor in that they are considerably larger and produce heavier, longer fleeces in which the staples are more distinct.

Like the other long-wool breeds, the Dartmoor was considerably improved years ago by the Leicester, Lincoln blood also being introduced about this time.

The breed has never been very widely distributed, but they have proven an excellent sheep in their native moor. Their extreme hardiness enables them to withstand the rigors of the winters of the Dart-

moor, principally upon grass, but sometimes supplemented with a little hay. They can withstand a very wet climate. Only the show sheep receive grain or roots.

Wrightson says, "The Dartmoor sheep of to-day are a large, long-wooled variety, rivaling in size the Cotswold, Lincoln, or Romney Marsh breeds." With the exception of their hardiness they have largely lost the characteristics of a mountain breed. They are preferably hornless, but the rams occasionally have short horns, about 2 inches long and extending backward from the head. The face is gray, with black spots frequently about the muzzle and on the ears. Dun spots are objectionable. The wool is long, sometimes reaching a length of 15 inches in 12 months, of excellent quality, and very strong. It extends over the polls and well down over the hocks and knees, and a little appears upon the hind legs. Fleeces should weigh about 15 pounds.

The ewes are excellent mothers and produce early lambs when removed to more favorable climates, but few fat lambs are produced in the Dartmoor.

Wm. Cooper & Nephews imported 58 head of Dartmoors in 1909 for John Rawlins, of Forest, Ontario. Soon afterwards these sheep were sold and taken to Utah and Wyoming. They greatly resemble a gray-faced Cotswold and are of about the same size as that breed. They are characteristically ewe-necked. The fleece is of exceptional length and quality, and the ringlets are close and distinct. The Dartmoor has been used for the production of extra long wool to a limited extent, and they seem especially suitable for this purpose.

However, too few of this breed have been imported and not enough trials have been made to warrant any extended discussion as to their general fitness to American conditions.

BLACK-FACED HIGHLAND.

The Black-faced Highland is much famed in poetry and legend, and there are many explanations as to its origin. Among these are that the original stock was cast ashore from the Spanish Armada, an already overworked theory, and that they are the result of a cross between a sheep and a goat, something which has never been proved to exist, and from present knowledge seems impossible. Other theories are that they came from the mountainous part of England to Perth and Dumbarton, and that the original flock was placed upon the estate of King James IV, in Ettrick Forest, about 1503. Either of these latter two theories is at least possible. At any rate, these black-faced sheep have been well known for a century and a half, and the dispute as to their origin would indicate that they had ranged the Highlands for a still longer period.

After the establishment of the breed in Perth and Dumbarton, they colonized the neighboring counties and eventually spread over the Highlands of Scotland and much of the mountainous region of England. About a century ago, the Black-face was forced to retreat before the Cheviot, but it later reestablished itself, because of its greater hardiness. These two breeds practically comprise the sheep sections of the Scotch shows. David Dun, of Kirkton, greatly improved the breed, and he has been referred to as the Scotch Bakewell.

Cross-bred or grade Black-faced Highland sheep meet with much favor in Scotland. Crossing a Leicester ram upon the ewes produces what is known as a "cross" or "mule"; a Cheviot ram upon Black-faced ewes produces a "half-long."

Hugh Brodie, in June, 1861, made an importation of one ram and two ewes to New York Mills, N. Y. In 1867 Isaac Stickney made an importation into Illinois. They have not been especially popular, and consequently their distribution is quite limited. The New York State Fair is the only show in this country where these sheep are exhibited.

The breed would probably succeed in some of the mountainous parts of this country and also in Alaska, as they thrive excellently upon coarse pasture, but upon the more fertile, arable districts they are out of place and will not yield returns comparable to those of the breeds adapted to the latter conditions. They are a very picturesque breed and are suitable for keeping in parks, and have been used for this purpose to a certain extent.

The Black-faced Highland is the hardiest of all British breeds of sheep. They are small and very active, but not so restless as the Welsh Mountain sheep. Their faces and legs are generally free from wool and covered with black or black and white hair. They usually have a small amount of wool about the top of their heads. When mottled, the markings are always very distinct. The form is rather inferior because of their habits of life, but the mutton is of the highest quality. Rams and ewes in breeding condition should average about 150 pounds and 125 pounds, respectively.

The fleece is of very low quality, lacking fineness, luster, and uniformity. It usually contains considerable hair and kemp and is classed as carpet wool when sold upon our markets. The staple is usually quite long, occasionally attaining a length of 15 inches. Both sexes are horned, and it is sometimes necessary to cut off part of the horns to prevent their growing into the head and to allow them to eat, otherwise they could not get their heads upon the ground.

The ewes are good mothers and fair milkers, and the lambs are very strong at birth. These sheep show a marked fondness for their homes. It is claimed that they have traveled 60 miles and swam rivers to return to their native haunts.

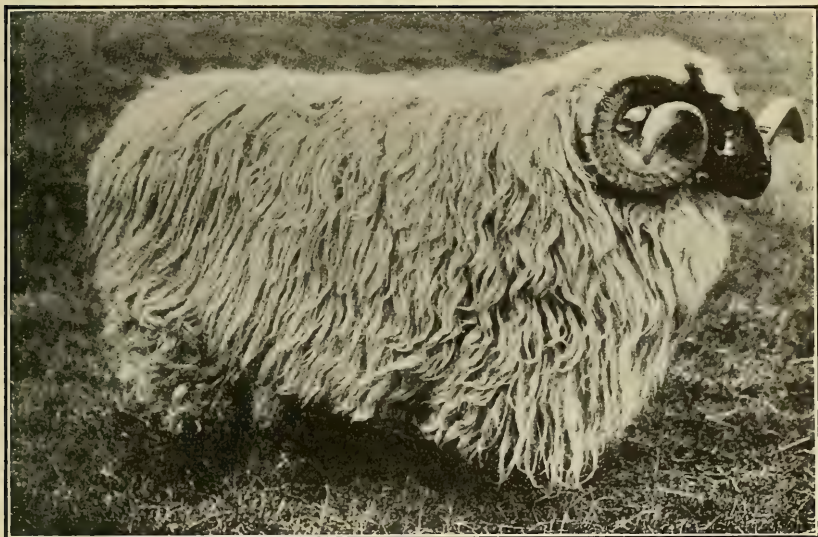


FIG. 1.—BLACK-FACED HIGHLAND RAM.



FIG. 2.—BLACK-FACED HIGHLAND EWE.



FIG. 1.—KARAKULE RAM.



FIG. 2.—KARAKULE EWE AND LAMB.



FIG. 1.—PERSIAN RAM.



FIG. 2.—PERSIAN EWE AND LAMB.



FIG. 1.—BARBADOS RAM.



FIG. 2.—BARBADOS EWE.

If Black-faced ewes are fed heavily when they are with lamb, there is danger of growth of the horns of the male lambs to such an extent that death may result to both ewe and lamb.

A meeting of the breeders of Black-faced Highland sheep was held January 31, 1907, at New York City, and the American Black-faced Highland Sheep Association was formed. This organization looks after the breed in America.

THE KARAKULE OR ARABI.

The Karakule sheep has sprung into prominence because of the increase in demand for Persian lambskins. The Persian lambskin is known by such other trade names as krimmer, astrachan, and broad-tail, these different terms representing somewhat different grades, and is the product of the Karakule or Arabi lamb. This demand has increased immensely during the last 15 years, one New York house alone importing from 200,000 to 250,000 skins per year.

These skins are practically all imported from Bokhara and the neighboring districts of Russian Turkestan. The large foreign demand for skins has caused a great deal of crossing, this having been practiced to such an extent as to threaten the existence of the breed. A well-known authority on this sheep made the statement that there were not more than 5,000 purebred Karakules in existence, and that these were mostly to be found upon the estates of the Bokharan noblemen.

There has been a law passed forbidding the exportation of Karakules from their native country, and this is rigorously enforced. This edict is said to have been passed for religious reasons, but the desire to keep a monopoly upon the fur industry was probably also a reason for its enactment.

The Karakules are one of the fat-tail breeds. The caudal appendage is broad, flat, and tapering toward the end. The lower vertebrae are curled and twisted to such an extent that they resemble a corkscrew, and the entire appendage is used primarily as a storehouse for fat.

The head is strikingly characteristic of the breed, the face being narrow and the top and fore part of the skull much rounded. The rams ordinarily have beautiful outspreading spiral horns, but the ewes are generally hornless. The ears are small and pendulous, especially so in the lambs. The face and legs of the adults are covered with short, lustrous black hair, while the wool of the body is coarse, long, and varies in color from gray to black. Very hard outer wool and the absence of soft underwool are said to be indications of purity of blood.

The breed is noted for its extreme hardiness, and it is able to exist and thrive under very adverse conditions. In Bokhara the sheep

are kept entirely in the mountains during the summer and until snow flies; then they are driven to the lowlands, where they are wintered.

The mutton is said to be the most palatable of any breed, and the fat is also considered a delicacy by the Bokharans, being used by them instead of butter.

The lambs when dropped are strong and active, usually jet black. The wool has a high luster and should be closely curled over the entire body, down the legs, and well over the head. Occasionally golden-brown lambs are dropped, the color of the prophet Mohammed. These are said to be especially highly valued by certain tribes and to have exalted the Karakule to its sacred position. Intermixed gray hairs among the black also rarely occur, producing a skin resembling somewhat the Siberian silver fox.

When used for producing fur, the lambs must be killed when not older than 10 days, as the curls open after this period. Formerly the skin of the unborn lamb was used, necessitating the killing of both the ewe and the lamb, but this practice no longer prevails. After the lambs are killed the ewes are milked for a time, and the famous Brinza cheese is made from the product. The value of superior skins ranges from \$10 to \$15.

The first Karakules to come to America were those brought over by Dr. C. C. Young, of Belen, Tex., in December, 1908. This shipment originally consisted of 15 head—3 bucks and 12 ewes. Seven lambs were born during the journey. Another importation was made by the same person in November, 1912, consisting of 19 head—13 bucks and 6 ewes. One buck died in quarantine and 5 lambs were born, making a total of 23 head.

A number of flocks have been established in this country from this stock, in Texas, New Mexico, and Kansas, and recently a flock has been taken to Prince Edward Island. The Department of Agriculture used two of these rams for experimental purposes, crossing them upon ewes of the American Merino, Barbados, Cotswold, and Cheviot breeds. Half-blood skins were produced, but they were of poor quality. The crossing upon the Merino and Cheviot breeds has helped to establish the fact that the tight-wool breeds are unsuited for the production of fur.

With the Barbados cross there still seems to be possibilities. The second cross, resulting in a three-quarter blood Karakule lamb, shows considerable improvement, and if the high fecundity of the Barbados can be maintained in the higher crosses it may be that this work will prove valuable in increasing the amount of Karakule breeding stock.

Of the long-wool crosses with the Karakule, the Lincoln has given the best results.

The Karakule has been tried in Texas, Kansas, Maryland, and a number of other places in America, and in every instance has proven extremely hardy. There is no doubt but that the breed will thrive in

our climate, and from the results that have already been obtained in fur production it seems quite likely that the industry will be more permanently established in America.

THE PERSIAN SHEEP.

The first importation of Persians to the United States took place in June, 1892. Truxton Beale, United States minister to Persia, brought over six individuals, which he presented to Secretary of Agriculture Rusk. After changing hands several times, they were finally taken to C. P. Bailey's ranch, at San Jose, Cal. A number of small colonies were disseminated from the parent flock through various Western States, and they were used for crossing upon the fine-wool range sheep, producing what is known as the Persiarino. The cross was said to result in an improvement in mutton form and for a time was popular in a limited way, but less is heard of it during late years. Another importation was made in 1910, consisting of a buck and two ewes.

The Persians that have arrived upon our shores have varied considerably in color. Some have dark faces, while others are mostly white. The mutton is considered of good quality, and the tail is a delicacy with the Turks, but it is not very highly appreciated by the Americans. The wool is rather long and coarse and grades low quarter blood combing or carpet wool.

It has been claimed that the Persian lambskin industry is based upon this breed, but present information shows that the so-called Persian lamb does not come from Persia but from Bokhara and that the young of the Karakule sheep, mentioned elsewhere in this publication, produce these skins.

In 1904, just previous to the Louisiana Purchase Exposition, the breeders of Persian sheep in America are said to have organized a society for the promotion of the breed. They have not manifested very much activity of late, the society apparently having ceased to exist.

THE BARBADOS.

The Barbados, or "Woolless," sheep were imported by the United States Department of Agriculture from the Island of Barbados, West Indies, in 1904. This importation consisted of one ram and four ewes, and represented a present to the Department. The original stock is supposed to have come from Africa. They are a rather small breed, 52 ewes at the Government Farm at Beltsville, Md., ranging from 63 to 115 pounds in weight and averaging 85.4 pounds. Bucks weigh from 125 to 150 pounds.

In mutton qualities, these sheep are very deficient. They are narrow and upstanding, fairly fine in bone, but have very long necks. They are much cut up in the flanks, deficient in heart girth, have a very droopy rump, with a low setting of the tail, are deficient in the

twist, and have poor development of the hind quarters. They are lacking in covering, not only over the ribs, but generally throughout the body, the bony framework being quite prominent.

They are covered with hair, varying in length from one-fourth inch to 2 inches. This is usually longer upon the top of the shoulders and neck, and it is more or less crimped. This coat of hair usually obscures the small amount of wool, which is short and very fine, but occasionally the wool projects out through the hair. During the spring and early summer the wool loosens and gradually curls up through the hair and is shed in tufts.

The head is rather attractive and is light or dark brown, with characteristic black bars above and below or alongside the eyes. The inside of the ears is black. The back and sides vary from a light fawn to a sealskin brown, and rarely there are markings of white. The belly and inside of the legs are black. The rest of the body varies in color from a light to a dark brown. Infrequently white spots occur.

The rams have a beard and also have long hair along the spine and extending from the lower jaw down along the brisket. They are usually hornless, but short horns occur occasionally. The redeeming features of the Barbados are their breeding qualities and their hardiness. Ewes breed at any season of the year and are remarkably prolific. One ewe produced six lambs at one time, although they all did not live, and twins and triplets are more common than singles. They are especially good milkers and the milk is very rich. The Government is crossing these sheep upon some of the mutton breeds for the purpose of determining the degree to which the fecundity is inherited in the cross-bred sheep and whether or not this quality can be utilized. These sheep have also been crossed with the Karakule for the production of lambskins, but the first cross has produced unsatisfactory results from the fur standpoint.

THE BARBARY SHEEP, OR AOUDAD.

The Barbary sheep have no commercial value. They are a wild breed; both sexes are horned, and the horns are beautifully banded and are marvels of symmetry. They are commonly seen in the zoological gardens and have been brought over to this country for a great many years for exhibition purposes. They have no wool, but are covered with light-brown hair. The bucks have a decided beard which extends well down their forelegs. Mature males weigh about 200 pounds and ewes from 125 to 150 pounds. The breed is quite prolific, one ewe at the Washington Zoo dropping four lambs in 11 months. They are very active and suspicious, especially with strangers.

APPENDIX.

Table showing the probable origin of the breeds of sheep in America.

American Merino.....	Spanish Merino.	Lonk.....	{ Penistone (?).
Rambouillet.....	Spanish Merino.		{ Black Faced (?).
Southdown.....	Sussex.	Ryeland.....	{ (?)
	{ Morfe Common.		{ Native Sheep.
Shropshire.....	{ Southdown.	Kerry Hill.....	{ Clun Forest.
	{ Cotswold.		{ Shropshire(?)
	{ Leicester.		{ Tunis.
	{ Wiltshire Knots.	Tunis (American type).....	{ Southdown.
Hampshire.....	{ Berkshire Knots.		{ Old Leicester.
	{ Southdown.	Leicester.....	{ Teeswater.
	{ Cotswold.		{ Old Cotswold.
	{ Cotswold.	Cotswold.....	{ Leicester.
Oxford.....	{ Hampshire.		{ Old Lincoln.
	{ Southdown.	Lincoln.....	{ Leicester.
Dorset Horn.....	{ Old Dorset.		{ Leicester.
	{ Somerset.	B. Leicester.....	{ Cheviot (?).
	{ Norfolk.		{ Old Romney.
Suffolk.....	{ Southdown.	Romney Marsh.....	{ Leicester.
	{ Hampshire (?).		{ Teeswater.
	{ Old Cheviot.	Wensleydale.....	{ Leicester.
Cheviot.....	{ Lincolnshire.		{ Old Dartmoor.
	{ Leicester.	Dartmoor.....	{ Lincoln.
Welsh Mountain.....	{ (?)		{ Leicester.
Exmoor Horn.....	{ Old Exmoor.		
	{ Leicester.		

Breeding of grand champions, reserve champions, and winners in the carcass contests at the International Live Stock Exposition, Chicago.

Year.	Grand champion.	Reserve champion.
1903	Grade Shropshire.	
1904	Grade Shropshire.	
1905	Southdown.	
1906	Southdown.	Grade Lincoln.
1907	Southdown.	Hampshire.
1908	Grade Shropshire.	Southdown.
1909	Southdown.	Hampshire.
1910	Southdown.	Hampshire.
1911	Shropshire-Leicester.	Shropshire.
1912	Shropshire.	Oxford.
1913	Shropshire-Leicester.	Oxford.

Breeding of grand champions, reserve champions, and winners in the carcass contests at the International Live Stock Exposition, Chicago—Continued.

WINNERS IN CARCASS CONTESTS.

Year.	Prize.	Wethers.	Wether lambs.
1900	1	Southdown-Shropshire.	Oxford.
	2	Oxford.	Southdown-Dorset.
	3	Shropshire.	Shropshire-Dorset.
1901	1	Grade Shropshire.	Southdown.
	2	Southdown (?).	
	3	Cotswold.	
1902	1	Grade Hampshire.	Grade Southdown.
	2	Grade Southdown.	Grade Shropshire.
	3	Grade Southdown.	Grade Southdown.
1903	1	Suffolk.	Grade Hampshire.
	2	Grade Shropshire.	Oxford.
	3	Southdown.	Grade Southdown.
1904	1		Grade Southdown (?).
	2		Southdown.
	3	Grade Southdown (?).	Grade Shropshire.
1905	1	Oxford-Southdown.	Grade Shropshire.
	2	Hampshire.	Grade Shropshire.
	3	Cheviot.	Grade Shropshire.
1906	1	Southdown.	Southdown.
	2	Southdown.	Grade Shropshire.
	3	Cheviot.	Dorset.
1907	1	Southdown.	Southdown.
	2	Southdown.	Hampshire-Rambouillet.
	3	Grade Southdown.	Grade Southdown.
1908	1	Shropshire.	Southdown.
	2	Shropshire.	Southdown.
	3	Southdown.	Shropshire.
1909	1	Southdown.	Southdown.
	2	Southdown.	Southdown.
	3	Southdown.	Grade Southdown.
1910	1	Southdown.	Cheviot.
	2	Grade Southdown.	Southdown.
	3	Southdown-Shropshire.	Southdown.
1911	1	Southdown.	Southdown.
	2	Cheviot.	Southdown.
	3	Grade Southdown.	Southdown.
1912	1	Southdown.	Southdown.
	2	Southdown.	Southdown.
	3	Cheviot.	Grade Shropshire.
1913	1	Southdown.	Southdown.
	2	Southdown.	Southdown.
	3	Southdown.	Southdown.

Table of information upon the breeds of sheep.

[F=fine wool; M=medium wool; C=coarse wool; W=woolless.]

Breed.	Rams.	Ewes.	Color of face.	Grade of wool.	Number recorded Jan. 1, 1913.	Class at the Royal, Eng-land.
Merino A type...F.	Horned	Polled	White	Fine clothing		
Merino B type...F.	do.	do.	do.	do.		
Merino C type...F.	do.	do.	do.	Fine combing		
Rambouillet...F.	do.	do.	do.	Fine clothing and combing.	1 500	
Southdown...M.	Polled	do.	Gray	$\frac{1}{2}$ -blood combing or clothing; $\frac{3}{8}$ -blood combing or clothing.	2 73, 305 30, 645	1839
Shropshire...M.	do.	do.	Soft black	$\frac{3}{8}$ -blood combing; $\frac{3}{8}$ -blood clothing.	385, 411	1860
Hampshire...M.	do.	do.	Black	$\frac{3}{8}$ -blood combing; $\frac{1}{4}$ -blood combing.	49, 640	1862
Oxford...M.	do.	do.	Brown	$\frac{1}{4}$ -blood combing; braid.	67, 280	
Dorset Horn...M.	Horned	do.	White	$\frac{3}{8}$ -blood combing; $\frac{1}{4}$ -blood combing.	15, 030	1862
Suffolk...M.	Polled	do.	Black	$\frac{1}{4}$ -blood combing; $\frac{3}{8}$ -blood combing.	2, 264	1880
Cheviot...M.	do.	do.	White	$\frac{1}{4}$ -blood combing	8, 115	1871
Tunis...M.	do.	do.	Mottled	$\frac{3}{8}$ -blood combing; $\frac{1}{4}$ -blood combing.	2, 530	
Welsh Mountain...M.	Horned	do.	Slightly tanned or speckled.	$\frac{1}{4}$ -blood combing		1885
Exmoor Horn...M.	do.	Horned	White	do.		
Ryeland...M.	Polled	Polled	do.	do.		1870
Kerry Hill...M.	do.	do.	Mottled	do.		1907
Lonk...M.	Horned	Horned	do.	Low $\frac{1}{4}$ -blood combing.		1877
Shetland...M.	Either	Either	Black, white, or both.	Probably $\frac{1}{2}$ -blood combing.		
Leicester...C.	Polled	Polled	White	Braid and low $\frac{1}{4}$ -blood	15, 913	1839
Cotswold...C.	do.	do.	Light gray or speckled.	do.	74, 455	1862
Lincoln...C.	do.	do.	White, slightly speckled.	do.	26, 122	1862
Romney Marsh...C.	do.	do.	White	Low, $\frac{1}{4}$ -blood combing	124	1862
Wensleydale...C.	do.	do.	Bluish white	Braid		1883
Dartmoor...C.	do.	do.	Speckled black and white.	do.		1875
Black-faced Highland, C.	Horned	Horned	Mottled, black and white.	Low, $\frac{1}{4}$ -blood combing and carpet wool.		1872
Karakule...C.	do.	Polled	Black	do.		
Persian...C.	do.	do.	Mottled or dark	do.		
Barbados...W.	Either	do.	Black and fawn			
Barbary...W.	Horned	Horned	Brown			

¹ Von Homeyer Association.² American Association.**PARTIAL INDEX OF RECENT PUBLICATIONS ON THE BREEDS OF SHEEP.**

Sheeping Farming, by John A. Craig. New York, The Macmillan Co., 1913.

Types and Breeds of Farm Animals, by C. S. Plumb. New York, Ginn & Co., 1906.

Farm Livestock in Great Britain, by Robert Wallace. Edinburgh, Oliver & Boyd, 1907.

Sheep Breeds and Management, by John Wrightson. London, Vinton & Co., 1895.

The Sheep and its Cousins, by R. Lydekker. London, George Allen & Co., 1912.

Cattle, Sheep and Pigs, by F. T. Barton. London, Jarrold & Sons, 1912.

Modern Sheep, Breeds and Management, by "Shepherd Boy." Chicago, American Sheep Breeder Co., 1907.

Sheep Farming in America, by Joseph E. Wing. Chicago, Sanders Publishing Co., 1907.

Sheep Management, by Frank Kleinheinz. Cantwell Printing Co., Madison, Wis., 1911.







BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE

No. 95.



Contribution from the Bureau of Entomology, L. O. Howard, Chief.
July 9, 1914.

INSECT DAMAGE TO THE CONES AND SEEDS OF PACIFIC COAST CONIFERS.¹

By JOHN M. MILLER,

Entomological Assistant, Forest Insect Investigations.

INTRODUCTION.

Recent damage by insects to the cones and seeds of conifers has been brought to notice by the collectors of forest seeds. Compared with other commercial seeds the market price of forest seeds is high, owing to the limited demand, the special knowledge required for their collection, and the irregular production of conifer crops. A heavy percentage of damage materially decreases the profits of seed collection and may result in time and money fruitlessly spent. Seed that is badly infested or damaged by insects can not be sold to reliable dealers when its character is recognized.

It has been found that insects sometimes destroy practically all of the seed crop of a tree species in one locality in a season. In this respect insects have a certain relation to the future supply of timber, as the natural reproduction of forests is assured only by the production of a prolific supply of uninjured seed. (Pl. I, fig. *a*.) The artificial reforestation of denuded areas must also depend upon the collection of sound forest seed. An example of how insects may interfere with reforestation by a desired species has been furnished by the white fir on western national forests. Much of the seed of this species collected recently has been worthless for planting, a great percentage of this loss being due to insect damage in the cones and seeds.

Some information regarding insects that affect forest seeds and reproduction has been given in previous publications of the Bureau

¹ The names of the insects are not mentioned in this preliminary contribution because many of them are not yet named or described. When this has been done it is intended that a special bulletin on the subject shall be prepared by the same author.—A. D. HOPKINS, in *Charge of Forest Insect Investigations*.

NOTE.—Information regarding insects that seriously affect forest seeds, especially in the coniferous forests of the Pacific coast. A practical paper, of interest to seed collectors, dealers in forest seeds, and planters of forest areas; of particular application to Pacific coast regions.

of Entomology.¹ This bulletin gives further facts regarding the character and extent of damage to the seed of coniferous forests of the Pacific slope. It also furnishes preliminary information on the more important groups of insects causing this damage, and their habits, that it may be available to seed collectors during the present spring and summer.

CHARACTER AND CAUSE OF DAMAGE.

Damage to the seed of conifers is caused by various species of insects which feed upon the buds, flowers, immature cones and seed, and mature seed. Great damage is accomplished while the cones are immature and before the seed ripens. Cones which are infested, or "wormy," are often found when the areas for seed collection are being located. Wormy cones and seeds are caused by the adults and grubs of small beetles, the "worms" or caterpillars of moths, the maggots of gnats, and the larvæ of tiny wasps known as seed chalcids. In his work the seed collector usually encounters these immature stages of insects which depend upon the cone scales and seeds as their principal source of food supply. With the exception of the cone beetles the adult insect is seldom found in the immature cone. The insects may be found in almost any part of the cone or seed, the feeding habits varying much with the different species. In many cases the presence of these insects in the cone is evident and may be recognized by the peculiar type or class of injury. Where this is the case the damage may be approximately estimated during the summer.

With the more important seed-infesting insects the damage will be recognized in one or more of the following classes:

BLIGHTED CONES.²

The cones are sometimes killed when small and immature. As a result they wither and dry, and none of the seeds fill. Cones so affected are often described as blighted. Most of the injury of this character occurs in the cones of pine and is caused by the cone beetles. The attack is usually on the second-year cones, although the small first-year cones are sometimes killed. Some of the cone worms, also, bore into the cones in such a manner as to kill them and cause the same blighted condition. Sugar-pine cones attacked by the beetle nearly always fall to the ground during July and August. The cones of other species usually adhere to the tree for a winter or two. Damage of this type is easily recognized and can be estimated after the middle of July.

¹ Hopkins, A. D., Catalogue of exhibits of insect enemies of forests and forest products at the Louisiana Purchase Exposition, St. Louis, Mo., 1904. U. S. Dept. Agr., Div. Ent., Bul. 48, p. 13-14, 33, 1904.

Hopkins, A. D., Insect enemies of forest reproduction. U. S. Dept. Agr. Yearbook, 1905, p. 250-251, 1906. (Yearbook Separate 331.)

Rohwer, S. A., VI, Chalcids injurious to forest-tree seeds. U. S. Dept. Agr., Bureau of Entomology, Tech. Ser. 20, Pt. VI, p. 157-163, Feb. 10, 1913.

² Pl. I, figs. c1, d; Pl. II, figs. a, b.

WORMY AND ABORTED CONES.¹

In some forms of injury the cone is not killed, but may show masses of resin on the surface, castings caused by the feeding of larvæ, or little burrows through the scales, seed, and pith which contain small larvæ. In rare cases the cone may be aborted or deformed, forming a peculiar growth or shape. The cone, however, continues to grow and matures at the close of the season very much like a normal one. The seeds which are not mined or eaten by the insects fill and mature. Damage of this character may be found in practically all species of conifers. Much of it is caused by the caterpillars of different species of moths, some of which show nothing on the surface of the cone to indicate their work in the interior. The amount of damage to the seed of western yellow pine and Jeffrey pine throughout northern California and southern Oregon in 1912 was estimated by the writer to vary from 50 to 90 per cent of the crop.

WORMY SEED.²

This class of injury is found only in the seeds. The cone is not affected and shows no indication of the insect. Practically all of the reported damage of this type is caused by the larvæ of tiny wasps called seed chalcidids. A certain percentage of the seeds will be infested by a small, white, headless larva. The infested seeds are of normal size and appearance. The larvæ feed entirely within the inner lining of the seed. Damage of this type can be found only by cutting the seed open. Seeds which have been attacked are hollow and usually contain the small headless larvæ of the chalcidid. After the seed has been stored over winter some of the adults emerge, boring small clean-cut holes through the outer shell of the seed. This is the first external indication of these insects. Quite often seed infested by the seed chalcidid is collected and sold before the infestation is detected. Injury of this type is very common in certain species of fir, in which the damage has sometimes been found to run as high as 75 to 90 per cent of the cleaned seed. Species of seed chalcidids have also been found in the seed of western yellow pine and Engelmann spruce.

MAGGOTY CONES.

Many cones are injured by the maggots of flies and midges, some of which cause no appreciable damage to the seed. Small whitish or pink-colored maggots are found in the cones of nearly all conifers. They are the larvæ of tiny gnats, or midges. The pinkish maggots cause little masses of resin among the scales but do not seriously affect the seeds. The whitish maggots in fir cones cause considerable damage to both cone and seeds. (See Pl. III, figs. *a*, *c*.) They are often present in vast numbers and leave the cones when these are

¹ Pl. I, fig. *b*² Pl. III, figs. *b*, *d*.

spread to dry. They are among the most common insects noted in the work of seed collecting.

IMPORTANT GROUPS OF SEED-INFESTING INSECTS.

There are four important groups of insects which cause practically all of the serious damage under the four classes described.

CONE BEETLES.

Cone beetles are small, dark, cylindrical beetles which attack the cones of pines. The cones are killed by the attack of the adult, which bores a small tunnel into the axis to deposit its eggs. (Pl. II, fig. *b 1*.) The larvæ (Pl. I, fig. *d*) feed on the seeds and scales of the withering cone and develop to the beetle stage within the dead cone, where the beetles usually remain over winter. The attacks of several species of these beetles are very common in western yellow pine and sugar pine. The damage to crops of sugar pine is considerable, as these beetles have been noted in some seasons to kill from 25 to 75 per cent of the cones over large areas.

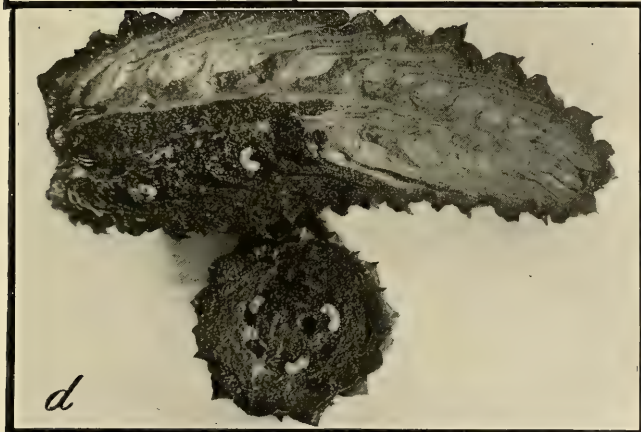
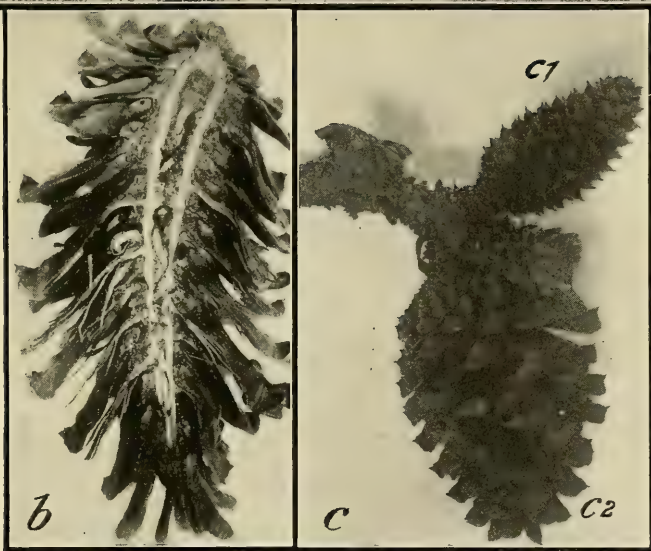
CONE WORMS.

Cone worms are most frequently met with in the cones in the caterpillar stage. They represent several species of moths which infest the cones of pines, firs, hemlocks, and spruces, and even the seed of incense cedar has been found to be attacked by the tiny larvæ. The moths are small and in most species dull colored and inconspicuous. The small white larvæ of one species are very common in the cones of western yellow pine and Jeffrey pine. They feed upon the seeds and scales without killing the cone and overwinter as larvæ and pupæ in galleries in the pith of the cone axis. (Pl. I, fig. *b*.) Another species is a very common enemy of Douglas fir seed on the Pacific slope. The larvæ mine a gallery through the scales, leaving an opening at the surface through which resin and larval castings exude. The pupæ overwinter near the axis in resinous cocoons among the scales. Nearly all species feed without killing the cone, but a large caterpillar feeding on western yellow pine sometimes kills the immature cone, the damage resembling that of the cone beetle.

SEED CHALCIDIDS.

The adults of seed chalcidids are tiny wasps (Pl. III, fig. *d*). The larvæ (Pl. III, figs. *b*, *d*) live within the seeds, apparently developing as the seeds grow, so that the infested seeds reach normal size and

EXPLANATION OF PLATE I.—*a*, Photograph near Bray, Cal., showing cones of western yellow pine on ground, but poor reproduction; *b*, mature western yellow pine cone, showing pith occupied by the cone worm and seeds destroyed by it; *c 1*, blighted western yellow pine cone caused by the cone beetle; *c 2*, normal cone; *d*, young living western yellow pine cone, greatly enlarged, to show character of damage by the cone beetle and its larvæ. (Original.)



INSECT DAMAGE TO REPRODUCTION OF WESTERN YELLOW PINE.

[For explanation of plate see note at foot of page 4.]

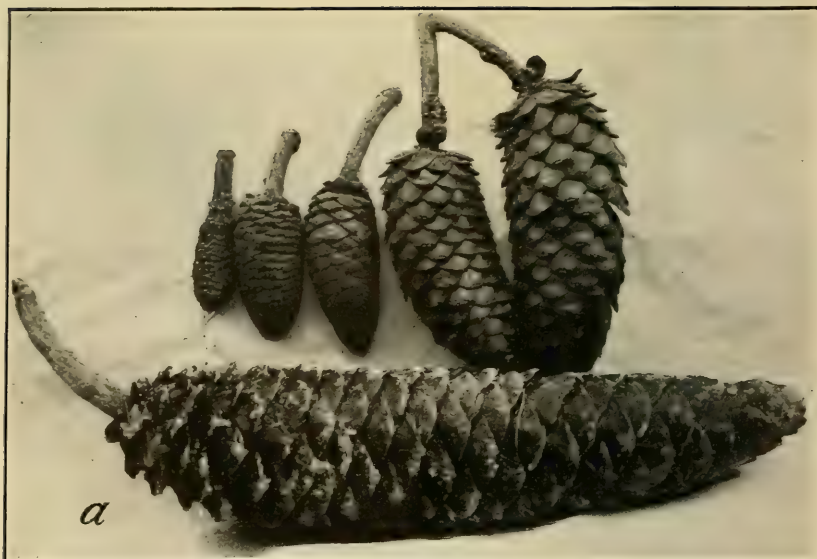


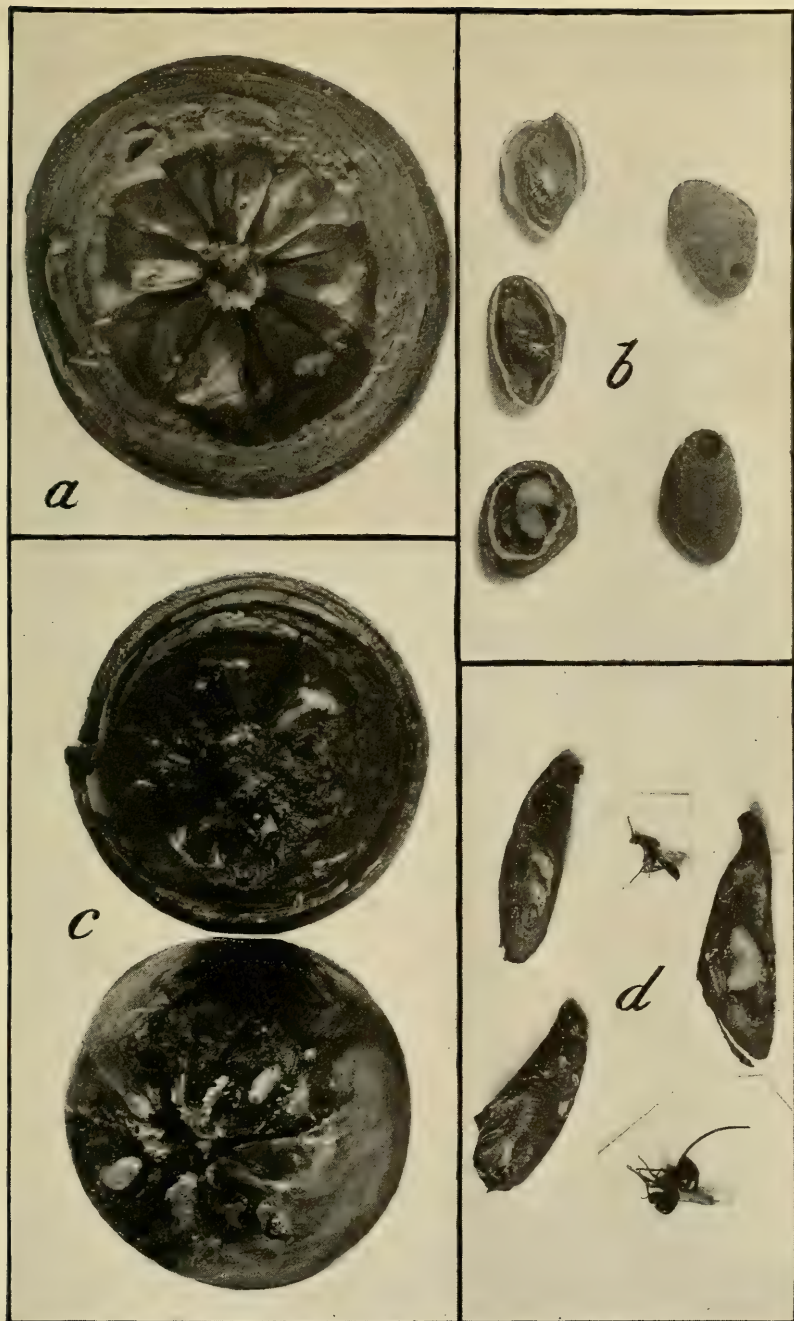
FIG. A.—SUGAR-PINE CONES ATTACKED BY THE CONE BEETLE AT DIFFERENT STAGES OF GROWTH OF THE CONE. (ORIGINAL.)

[The longer cone, which is about 14 inches long, resisted attack, while the others were killed.]



FIG. B.—LONGITUDINAL AND TRANSVERSE SECTIONS OF SUGAR-PINE CONES, NATURAL SIZE, SHOWING PRIMARY EGG GALLERIES, B1, MADE BY THE CONE BEETLE. (ORIGINAL.)

WORK OF THE CONE BEETLE IN SUGAR PINE.



WORK OF A CHALCID IN SEEDS OF PACIFIC COAST CONIFERS.

a, Cross section of sound, mature white fir cone with unaffected seed; b, yellow pine seed, enlarged, infested by larvæ and newly transformed adults of a seed chalcid; two unopened seeds show exit holes made by these insects; c, cross sections of two maggoty white fir cones; d, male and female adults of seed chalcid, larva in opened seed of red fir (*Abies magnifica*), and exit holes in two other seeds of same. (Original.)



form. There are several species, one of which is very destructive to the seed of Douglas fir, white fir, and red fir.

FIR-CONE MAGGOTS.

Fir-cone maggots are the larvæ of small gnats which have been found in the cones of white fir, red fir, and alpine fir. They mine through the scales and seeds, causing great damage. The larvæ do not winter in the cones but burrow into the ground as soon as the cones fall. They form small puparia within an inch or so of the surface, and there they overwinter.

ADAPTATION OF THE INSECTS TO THE INTERMITTENT CONE-PRODUCING HABITS OF THE HOST TREES.

There is a general life cycle for most of the cone-infesting insects corresponding to the period required by the host tree to develop the seed crop. The adult insect, whether beetle, moth, fly, or seed chalcid, deposits the eggs in the spring or early summer while the cones are small and undeveloped. With some species the attack is such that the cone is killed; with others the attack and feeding of the larvæ do not interfere with the growth of the cone, which matures at the normal time, although much of the seed may be destroyed. The feeding of the larvæ ceases, however, when the cone matures, usually during September. The insects then undergo a long dormant period either as larvæ, pupæ, or new adults. This dormant period continues until there is another crop of cones in a proper condition for attack; that is, the soft, immature cones which are found in the spring or early summer. Some insects pass this dormant period in the pith of the cones or in resinous masses among the scales. Other species leave the cones and form the pupæ in the ground or in débris on the surface.

The intermittent character of the seed production of conifers is a well-established fact.¹ A few cones are produced every year, but a good crop occurs at intervals of from two to five years. The years of total failure are known as "off years." It is evident that if the entire brood of any of these species of cone-infesting insects emerges annually, it will sooner or later encounter an off year of the host tree. This would mean the complete failure of the food supply for one generation and would result in the almost complete extinction of the species within the forest area affected by the crop failure. As a matter of fact, observations show that this seldom happens. All the individuals of a brood of overwintered insects do not emerge the following spring. Many of them do emerge after the first winter, but a large percentage of the brood, in some species 50 per cent or more,

¹ U. S. Dept. Agr., Forest Service, Bul. 98, p. 13, Nov. 18, 1911.

continues for another year in the same condition in which the first winter was passed. Usually this retarded part of the brood emerges at the end of the second winter or spring.¹ This is an adaptation which to a certain extent accounts for the continued infestation of certain species of insects in the seed of forest trees. In the case of a species of gnat which infests the cones of white fir it was found that the entire brood of insects which destroyed the 1911 crop of seed on an area in northern California did not emerge at all in the spring of 1912, but remained in the pupal state through the summer of 1912 and the following winter. The adult flies finally emerged in the spring of 1913. Under this adaptation it would appear that only a continued failure of the crop through a series of years would result in the reduction of the numbers of the infesting species on a forest area. Undoubtedly other agencies are responsible for the uninfested condition of the seeds of certain trees during some seasons.

INDICATIONS OF INSECT DAMAGE.

Attack of the cone beetle in the seed crop is indicated by a small entrance hole at the base of the cone, with castings or small pitch tubes, during the early summer; later, by the brown, withered appearance of the cone.

The attack of the cone moth may sometimes be recognized by little masses of pitch and larval castings on the surface of the cone and sometimes by withered cones, but it is best to look for the caterpillar among the scales and in the seed and pith. It is always best to cut the cone open, sectioning it several different ways, in making the examination.

The attack of the fir-cone maggot can also be found by cutting or breaking the cone open. The larval mines will be found in the scales and seeds, in which will usually be found the small, white, active larvæ.

The seed chalcidids show no external evidence, and the seeds must be sectioned or otherwise opened to find the larvæ of these insects. Unless test is made the amount of damage can not be determined, and seed that is badly infested may be taken as sound.

METHODS OF PREVENTING LOSSES.

There are areas of light infestation by these insects in certain species of trees, and there are areas where the damage is very heavy. The amount of infestation in the seed may also vary with succeeding seasons. A careful examination of the cones before the seed matures, during July and August, will usually reveal immature stages of the seed-infesting insects. If cones of the past season are examined during the winter and spring, they will indicate whether or not the

¹ This retarded emergence has not been observed in the case of the cone beetles, but it has been observed in the more important cone worms, fir-cone maggots, and seed chalcidids.

area is infested by these insects. In the collection and cleaning of forest seeds there is opportunity for use of the information which is now being gathered on this subject. An intelligent selection of the seed-collecting areas will prevent much of the loss due to gathering seed which is afterwards found to be infested or worthless.

A count of the number of infested cones and of damaged seeds will give a clue to the percentage of damage in the crop. Whether or not the damage is sufficient to make collection of the seed unprofitable on the area will have to be determined by the collector.





BULLETIN OF THE U.S. DEPARTMENT OF AGRICULTURE



No. 96

Contribution from the Bureau of Entomology, L. O. Howard, Chief.

July 22, 1914.

(PROFESSIONAL PAPER.)

THE TEMPERATURE OF THE BEE COLONY.¹

By BURTON N. GATES, Ph. D.,

Formerly Apicultural Assistant, Bureau of Entomology.

INTRODUCTION.

There has been a decided need of accurate knowledge of the temperatures and changes in weight of colonies of bees, particularly ring the winter. Previously existing data have not been gained under controlled conditions, but generally by casual observations, limited in number. Most of the previous work has also been for a short period of the year. In this work an effort has been made to get more reliable information by collecting data for practically the cycle of a year. The knowledge of the changes in temperature and weights is needed in a careful study of methods for successfully wintering bees. This is one of the greatest difficulties which the beekeeper has to meet, and it is hoped that the present work may furnish data for a further study of the wintering problem. The scope of the work here recorded is indicated by the following figures:

Period of experimentation, October 22, 1907, to September 26, 1908.

Number of observations, 2,576+.

Number of separate readings, 20,000+.

APPARATUS.

The apparatus was constructed to meet emergencies which might arise, which accounts for its many parts. It was planned so that the complete apparatus could be upon the scales at all times, thus obviating complications from corrections in weighings.

THE SCALES.

A finely adjusted platform scales was specially constructed, which registered with a sensitivity of 10 grams to a maximum of 200 kilograms. It was expected that it would be possible to record

¹ This report of work done for the Bureau of Entomology has been accepted by the faculty of Clark University, Worcester, Mass., as a dissertation in partial fulfillment of the requirements for the degree of doctor of philosophy, and accepted upon the recommendation of Dr. C. F. Hodge. The author has been appointed to the position of assistant professor of beekeeping, Massachusetts Agricultural College.

NOTE.—A study of the effects of temperature on bees, and of interest to beekeepers generally.

slight changes in consumption or increase of stores. By means of a double beam it was possible to counterbalance for extra thermometers or other small special apparatus which might be added temporarily, without necessitating a correction of the hourly readings. The scales were found to be relatively satisfactory, but in times of heavy wind extra precaution was necessary in order to overcome the influence of drafts on the scales. In winter this could easily be

accomplished by closing the door of the shed in which the experiment was carried on. For outdoor work, however, some difficulty was experienced, as will be explained. The agate-set bearings were also sensitive to jar, which was constantly guarded against.

THE THERMOMETERS.

Seven mercury thermometers were used, of the type known as incubator thermometers, which have a long stem and can be read to fifths of a degree. One instrument, however, used to register the temperature of the outside air was an ordinary chemical thermometer. These instruments were standardized and were graduated to the centigrade scale.

THE HIVE AND ITS APPLIANCES.

Figure 1 illustrates the general appearance of the hive, showing the five stories. Only one of these was occupied by bees, as will be explained. The hive was of the standard 10-frame Langstroth

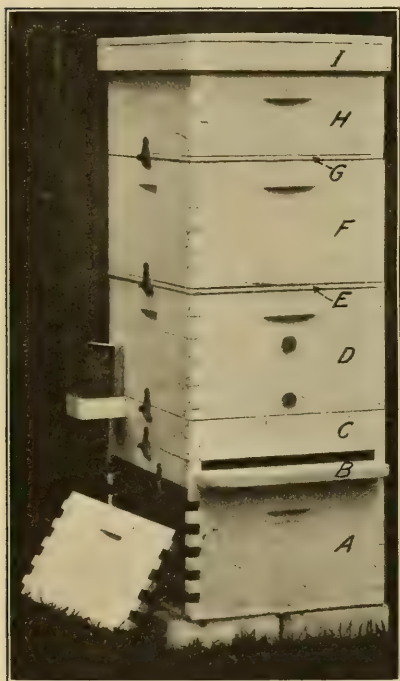


FIG. 1.—The hive used in the experiment on the temperature of the bee colony: *A*, storage chamber for accessories, with door; *B*, bottom board with entrance; *C*, collar with feeder; *D*, brood chamber; *E*, perforated zinc honey board; *F*, second story for surplus; *G*, thin board with holes for thermometers; *H*, case protecting thermometers *a-e*; *I*, outside cover.

type. Throughout the experiment it stood on the scales (fig. 2). The several parts were as follows:

A. The lower part consisted of a hive body with one side removed. To the bottom was nailed a thin cover board, which served as the floor of the compartment. The purpose of this chamber was to store fixtures, such as frames, "dummies," extra thermometers, and the like, while they were not in use. In this way it was unnecessary to compute in the weighings for any change in the apparatus. For example, in the winter, when four frames in the brood chamber were replaced by the "dummies," these were taken from the storage chamber and the frames hung in their place, without altering the weighings.

B. An ordinary bottom board.

C. This wooden collar contained the feeder and increased the space between the bottoms of the brood frames and the bottom board, thus allowing the insertion of a thermometer below the frames. The feeder was what is known as an Alexander feeder. The end may be seen extending out of the collar at the rear of the hive. In this projection, which was provided with a wooden cover, the sugar sirup is poured without disturbing the hive. The cover prevents drafts of air through the feeder.

D. Above the collar was the hive body in which the bees were located. The frames were spaced with metal spacers (fig. 3), and wedges between the central frames held all firmly in place. In this way everything was sufficiently secure to enable any possible manipulation, even to turning the hive upside down, should it be necessary, without displacing parts. The wedges also increased the space between the central frames sufficiently to allow for the insertion of the stems of thermometers. The gauge in frames 3 and 4 permitted the insertion of thermometer *e* (fig. 3). The frames were wired and filled with full sheets of foundation before insertion. Two holes were bored in the middle of the front above the entrance, for use in case it should become desirable to insert thermometers. Throughout the experiment these were closed with corks.

E. Between bodies *D* and *F* was a perforated zinc honey board.

F. A second body was provided in case more comb space should become desirable.

G. The top of the hive proper was covered with a thin cover. This, as is shown in figure 3, had four holes drilled in the median line and one directly over the rear part of the space between frames 3 and 4. Through these holes thermometers fitted in corks were inserted.

H. This was a special hive body used as a protection for the thermometers. One side, shown in figure 2, was removable so as to permit easy reading of the instruments. In this chamber and around the thermometers were two cushions of ground cork, for the protection of the tops of the thermometers and for the conservation of the heat of the cluster in the extreme of winter.

I. A metal cover.

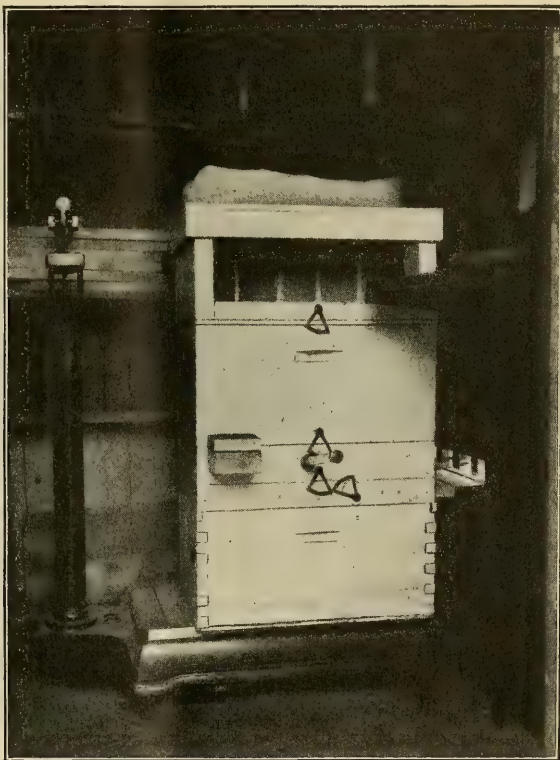


FIG. 2.—Hive on scales in shed where it was kept during the winter.

A series of clamps, which drew over screw heads, held the several parts firmly together, preventing the bodies from sliding and snapping the stems of the thermometers.

The "dummies" above mentioned consisted of ordinary frames into which boards were fitted snugly. These were used in the winter months instead of the two outside frames on either side of the hive, thus forcing the cluster to occupy six frames in the center of the brood chamber. In this way it was made certain that the cluster would not shift away from the thermometers during the winter. The

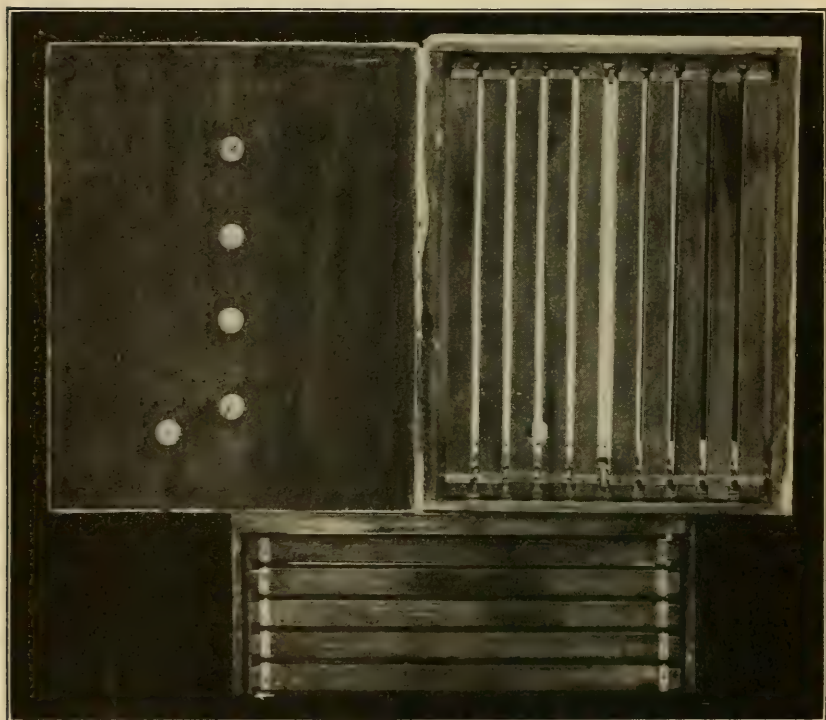


FIG. 3.—The hive from above, showing the spacing of the frames. The corks in the cover indicate the location of the thermometers.

"dummies" were removed when brood rearing became established in the spring. These were not intended primarily for protection and did not fit the hive tightly.

In order to eliminate the annoyance and possible complications from propolizing, all the interior wooden parts were varnished and polished to a piano finish.

It should be said that not all of the parts of the apparatus provided were pressed into service. The extra body, *D*, was not needed, and consequently the honey board, *E*, was not used. The outfit as

actually used and as it appeared in position until the writer was forced to move the experiment to the country in July, 1908, is shown in figure 2.

THE BEES.

Throughout the experiment Caucasian bees were used. Two colonies were necessary. The first drew out the foundation in the frames and was used during September and October, 1907. The second was hived in November, 1907, and served throughout the remainder of the experiment. This colony did not swarm.

THE ARRANGEMENT OF THE THERMOMETERS.

The thermometers were designated *a*, *b*, *c*, *d*, *e*, *f*, and *o*. Thermometers *a*, *b*, *c*, and *d* were inserted between the central combs. They were arranged at regular intervals, *a* being at the front of the hive and nearest to the entrance. Thermometer *e* was placed at the rear of the hive between combs 3 and 4, and was expected to represent the temperature of the margin of the cluster. Thermometer *f* was inserted beneath the frames through the collar, as is described above. Its purpose was to record the temperature of the air below the cluster and which was likely to be affected by currents from the entrance. Its bulb was directly below the central frames. The first five thermometers extended about 7 inches below the cover. The outside thermometer, *o*, was suspended close to the hive in such a way as to register the temperature of the air which surrounded the apparatus.

LOCATION OF APPARATUS.

The apparatus was installed in a shed on a third-story back piazza in southwest Washington, as is shown in figure 2. While the shed afforded shelter from storms, which was necessary for the protection of the apparatus and in taking observations, windows and door were left open, making the conditions relatively like out of doors. The shed was on the south side of the building.

In July, 1908, it was necessary to transport the experiment to College Park, Md. This, however, was found not to have affected the results. The apparatus was arranged in a situation comparable to the shed in Washington.

CHECK COLONY.

Besides the colony on the scales, in which the thermometers were suspended, a check colony in a hive with glass top and bottom was set up close by. The hive was constructed with a glass bottom board, and a wooden shield to cut out light. The cover was also of glass sealed to the hive, on top of which were several thicknesses of felt paper and an ordinary hive cover. By removing the bottom shield

and the top protection it was possible at any time of day or night to look between the combs at the cluster. These protective coverings were applied so as to be removed with the minimum jar. At night, or even in the daytime, by means of a reflector, lantern light could be thrown up between the frames. In this way the writer was able to watch from day to day the shifting of the cluster and the reaction of the bees to their environment and to compare this with the readings of the thermometers in the hive on the scales. It was necessary to maintain this check only during the winter period.

METHODS OF OBSERVATION AND RECORDING.

Since none of the instruments recorded automatically, it was necessary to make frequent readings of both the weights and temperatures. The experiment proper lasted from October 22, 1907, to September 26, 1908. The first colony, used to prepare the combs, was also under close observation, so that the whole period of experimentation was almost a year. Readings were taken at least every hour throughout the working day. Whenever the hive was manipulated, or when peculiar meteorological conditions prevailed, readings were taken half hourly, or even quarter hourly. On the average of about once in three weeks, by means of assistance, it was possible to take consecutive hourly readings for a period of two or three days. In this way practically the whole activity of the colony for a period of a year was recorded. During the summer months the readings usually covered a period of 14 hours daily.

The temperatures were read to fifths of a degree. Weighings were made to 10 grams. Every alteration or manipulation of the colony was recorded. Hourly changes in the weather and activity of the bees were also noted.

The readings were recorded on 12.5 by 20 cm. cards, the size standard to the office note file. Later from these tables the curves of the temperature and weights were plotted on millimeter cross-section paper, one sheet to a month. The method of plotting is obvious from examination of the several curves herein presented.

THE CONSUMPTION OF STORES IN WINTER.

At the outset of the investigations it was hoped by means of delicate scales, which have been described, that sufficiently accurate weighings could be made to show whether there is any correlation between the loss in weight and the temperatures of the cluster in winter. For instance, it was desirable to know whether there is any relation or rhythm in the consumption of stores to changes in temperature due to metabolism. It has not been possible to detect any such relations. Nevertheless several significant facts concerning the consumption of winter stores have been discovered.

The rate of consumption of stores, as is shown in figure 4, exhibits a relatively constant decrease from month to month. At the beginning of the season, before the cluster was well established, when bees were more active and before settled winter weather, food consumption was greater than in midwinter. As the season progressed, during February, for instance, consumption slackened. There are several factors which may account for this. In the first place, as the winter advanced there were fewer and fewer bees to be fed. The winter was also less severe, and consequently less generation of heat was necessary.

Humidity is another factor which noticeably influenced the daily weights for a considerable part of February. This also occurred

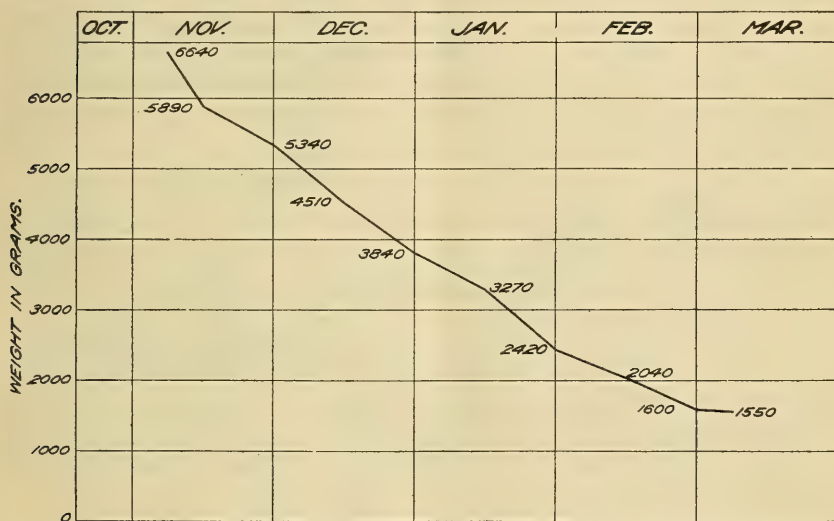


FIG. 4.—Graphic representation of the loss in weight of the bee colony from November 6 to March 7, due to the consumption of stores.

periodically in other months. Although condensation tended to prevent a drop or even to raise the curves during a period of bad weather, as will be shown below, the increased weight due to the condensed water vapor could neither be permanent nor affect the total loss of weight during so long a period as a month. Whatever water condensed during inclement weather would evaporate during the following days of fair weather. Thus, while the scales might register an increase during bad weather, consumption of stores was actually going on all the time, but could not be detected in the weights until fair weather had dispelled the moisture. Consequently the records of single days are less significant than the averages of a month or of the season.

There was, however, a gradual and constant lessening of the daily consumption of honey, as is apparent in Table I, which presents the monthly and average daily figures. From this table it will be seen that while in November the average daily consumption was 53.2 grams, in February the average was but 30 grams a day. For the entire winter 43.5 grams of honey were consumed, on the average, daily.

TABLE I.—*Monthly and average daily consumption of stores by wintering bees.*

Time.	Weight of stores.	Monthly loss.		Average daily loss.	
		Grams.	Pounds.	Grams.	Grains.
November (Nov. 6, 9 a. m., to Dec. 1, 9 a. m.—25 days)...	6,640 5,310	1,330	2.932	53.2	821
December (Dec. 1, 9 a. m., to Dec. 31, 9 a. m.—30 days)...	5,310 3,820				
January (Dec. 31, 9 a. m., to Feb. 1, 9 a. m.—32 days)....	3,820 2,470	1,350	2.976	42.2	651
February (Feb. 1, 9 a. m., to Feb. 29, 9 a. m.—28 days)...	2,470 1,630				
		840	1.852	30.0	463
Total loss for 4 months.....		5,010	11.045	43.5	671
Average daily loss.....					

TABLE II.—*Daily loss in weight of colony of wintering bees.*

Date.	Loss in grams.	Date.	Loss in grams.	Date.	Loss in grams.	Date.	Loss in grams.
Nov. 11	120	Dec. 10	+30	Jan. 10	70	Feb. 10	0
12	10	11	70	11	40	11	20
13	50	12	70	12	+10	12	20
14	70	13	60	13	30	13	0
15	50	14	20	14	50	14	+40
16	80	15	25	15	60	15	+20
17	90	16	25	16	40	16	130
18	60	17	60	17	50	17	20
19	10	18	40	18	50	18	40
20	70	19	40	19	40	19	+40

Although the foregoing figures represent the usual daily conditions, they do not by any means represent the actual daily consumption. As will be seen in Table II, there was no such degree of constancy as is represented by these averages. Taking the 10 days at the middle of each month, it is possible to represent prevailing conditions for that month. Thus the data of Table II are a fair representation of the actual variations as they occurred during the winter. It will be seen in this table that the daily variation in weight is all the way from a loss of 130 grams in some cases to no loss whatever or even an increase of 40 grams. Therefore it is hardly possible to assume that the weights of the entire hive will throw any light on the amount of honey consumed in a single day.

This increase in the weight of the hive during bad weather is a fact which, so far as the author is able to learn, has not heretofore

attracted attention. It can not be said in any wise that this is an increase in the amount of stores. The phenomenon usually accompanied wet weather or fog and must be attributed to condensation of moisture. In the check hive moisture was frequently seen collected on the glass top and even on the frames and bees, but there the conditions were perhaps less normal than in the experimental colony. Root¹ says that he has seen confined moisture cause icicles to form in the hive. The condensation may become so great in extreme cases as to cause the bees to freeze together in a solid block when chilled down by severe cold. (Root, pp. 332-334.)

Honey is well known to be hygroscopic, and if put into an ice chest or a damp cellar, it takes up moisture. Extracted honey has also been observed to accumulate enough moisture to dilute it considerably. In the present case the hygroscopic property of the honey can not be held wholly responsible for the increased weight, although it may have contributed. Following an increase of this kind, as has been mentioned, there was a marked decrease

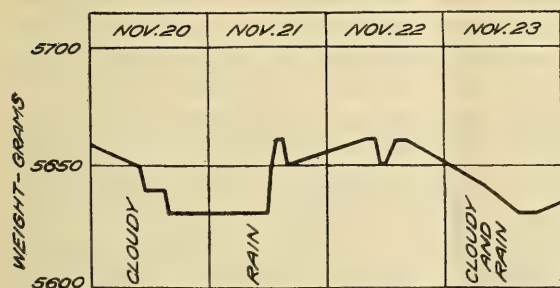


FIG. 6.—Curve showing changes in weight of the bee colony from Nov. 20 to Nov. 23.

wind. Then there came a marked decrease in weight, which not only compensated for the increase during the storm, but also showed that stores had been consumed constantly, although the weights

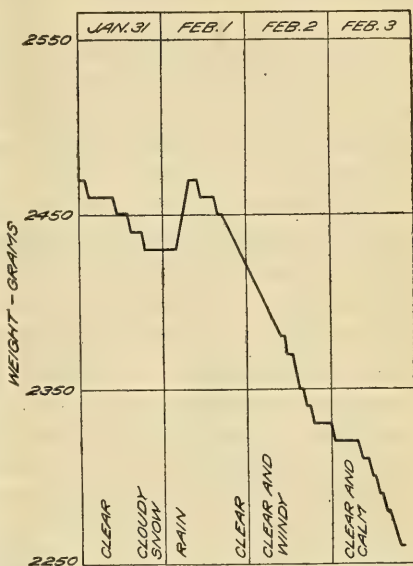


FIG. 5.—Curve showing changes in weight of the bee colony from Jan. 31 to Feb. 4.

with the coming of fine weather and dryness. For illustration, the increase of 40 grams on February 1 (fig. 5) occurred during the early part of the day, when it was raining. That afternoon and the following day there were fair weather and

¹ A B C and X Y Z of Bee Culture, 1908 ed.

failed to demonstrate it at the time. This same point is illustrated by the figures presented in figure 6. Such conditions suggest the complications which arise in attempting to correlate the colony temperature with the consumption of honey.

GENERAL PHENOMENA OF THE CLUSTER IN WINTER.

During the winter the bees are relatively quiet; the cluster expands and the bees fly only in the warmth of the warmest days. The heat maintained in the cluster has a general relation to the prevailing temperature of the air.

This relation of the cluster temperature to air temperature is especially evident in a comparison of the maximum and minimum temperatures of the several thermometers of the hive with the temperature at the outside thermometer, *o*. The daily maxima and minima were practically synchronous for all of the thermometers with the exception of *c*, which usually had its maximum when the temperatures registered by the other thermometers were lowest. Conversely, the minimum of *c* occurred when the outside thermometer and the others in the hive were at their highest points. This will be explained in detail under a following caption. With the exception of *c*, then, and for the particular conditions under which this colony was kept, the minima occurred daily some time between 6 a. m. and 12 m., but usually about 8 or 9 o'clock. The maxima occurred daily in the afternoon, usually between 2 and 4 o'clock.

While *c* registered the highest in cold periods, the temperature recorded by the other thermometers showed a similarity with the prevailing temperature of the air. Thus, in periods of cold, as for example in December, the thermometers in the hive as a whole registered lower than they did in warm periods. In warm periods, when the bees are able to expand the cluster and move about, the maximum cluster temperature lacked but a few degrees of the maximum summer temperature. This is repeatedly shown in figure 7; and in March, on a warm day, the temperature reached the extreme of 33.2° C. (91.76° F.). The temperature of the cluster did not fall below 17° C. (62.6° F.), and usually the bees did not permit the temperature of the cluster to fall below 20° C. (68° F.).

The amplitude of the fluctuations between the maximum and minimum temperatures showed a close relationship to the external conditions. In the center of the cluster, for instance, *c* registered much more constantly than the thermometers in the outside layer of the cluster. The daily oscillations of *c* were usually not greater than 1 to 5 or 6 degrees Centigrade. On the contrary, in the case of the other thermometers in the hive which were more affected by the rise and fall of the temperature out of doors, the amplitude of the oscillations was as great as 3 to 20 degrees Centigrade. The center of the cluster, therefore, shows more clearly the activities of the bees. The

active portion of the cluster has a higher and more uniform temperature than the other parts, while the outside layers are subject more directly to the fluctuations of the winter weather. Most of the following study of the winter conditions of the beehive will be based on the records of the center of the cluster.

It would naturally be expected that the heat radiating from the bees would tend to delay the effects of the penetration of the cold of the outside air on the cluster. In other words, it might readily be expected that the cluster thermometers would reach their maxima and minima later than the outside thermometer. However, this occurred seldom and only in severe weather, when the changes were rapid and considerable. Even then there was a delay of only an hour or two

at the most. This again suggests the sensitiveness and the responses of the cluster to the changes in the external air. The adaptation of the bees to changes in the atmospheric conditions will be more apparent when details are considered.

As has been suggested above, there was a tendency for the cluster gradually to maintain a higher temperature as the season ad-

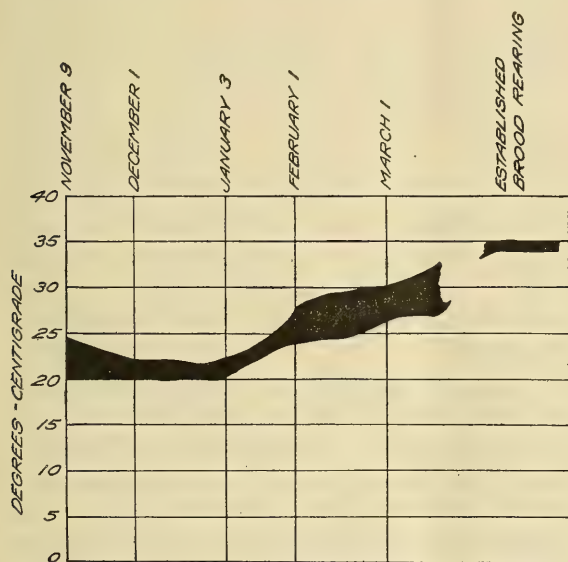


FIG. 7.—Schematic curve showing cluster temperatures of the bees during the winter and after brood rearing began.

vanced toward spring and the beginning of egg laying. The schematic curve, figure 7, presents graphically the conditions of temperature at thermometer *c* throughout the winter. It will be noticed that during the month of November, when the bees were less definitely and constantly clustered, the amplitude of the daily variation and the general temperature of the cluster were higher than in the succeeding months. This is also evident in the fact that the curve of the thermometer *c* at this time of the winter tended to follow the curve of the outside thermometer *o* to some extent. In December, however, there was a change in the course of the temperatures at *c*, in response to the change in outside conditions. The conditions remained more nearly constant from this time until egg laying commenced in the spring, except that as the weather tended to warm up at the approach

of spring the mean of the cluster temperature also raised. Finally when the days had considerably lengthened and were relatively warm, the amplitude of the cluster variations increased, as is shown in the schematic curve (fig. 7). When the summer season for the bees began, accompanied by the beginning of incubation, the temperature of the center of the cluster rose to 34° C. (93.2° F.) or 35° C. (95° F.) and continued practically at this level. For the winter, then, it might be said in a general way that the temperature prevailing for several days is in a measure an index of the temperature of the cluster.

TEMPERATURE BELOW FRAMES IN RELATION TO OUTSIDE AIR.

The thermometer *f*, situated below the bottom of the frames and cluster, as is shown in the general views of the apparatus (figs. 1 and 2), registered the temperature of the air at the bottom of the frames. It should have shown, if they were present, the effects of the cluster on the temperature of the air below the frames. It might be expected that the presence of the bees would have raised the temperature of the air in this part of the hive. For comparison with the other temperatures, thermometer *o* was hung in the shed in which the experiments were conducted, and registered the temperature of the air which enveloped the hive. Comparison of the readings of thermometers *f* and *o* reveal some significant facts not altogether in accord with the general belief of beekeepers.

During the winter as a whole these thermometers registered almost identically. Slight variations occurred, but only for a few hours at a time, and may be attributed to minor influences of the cluster, to peculiar atmospheric conditions, to drafts, and to the agitation of the bees. It should also be noted that the air which came in the entrance entered from outside the shed and the temperature of this air may not have been exactly that recorded by the thermometer *o*.

During the period of most protracted cold, from January 23 to February 1, when the outside air ranged about 0° C. (32° F.), thermometer *f* followed the outside temperature closely, and the course of the two curves is practically the same. In some cases, as for instance on January 26, thermometer *f* was slightly lower than the record of the outside air, which may possibly be explained by lack of ventilation or stagnation of the air of the hive. The lowest recorded outside temperature was -10° C. (14° F.). Since it was impossible to read these low temperatures on instrument *f*, and since the two curves are parallel so far as records were possible, it may be assumed that thermometer *f* would have registered almost the same as thermometer *o*.

During the warmest days and nights the recorded temperatures were the same. The maximum for the winter period came on March

15, when the outside thermometer reached 22.6°C . (72.68°F). In all the other winter months there were days when the thermometers registered only 2 or 4 degrees less.

In conclusion it may be said that throughout the season the temperature below the frame was practically the same as that of the outside air. Of special significance is the fact that the daily extremes, the maxima and minima, no matter what were the variations at other periods of the day, were usually identical. From these observations

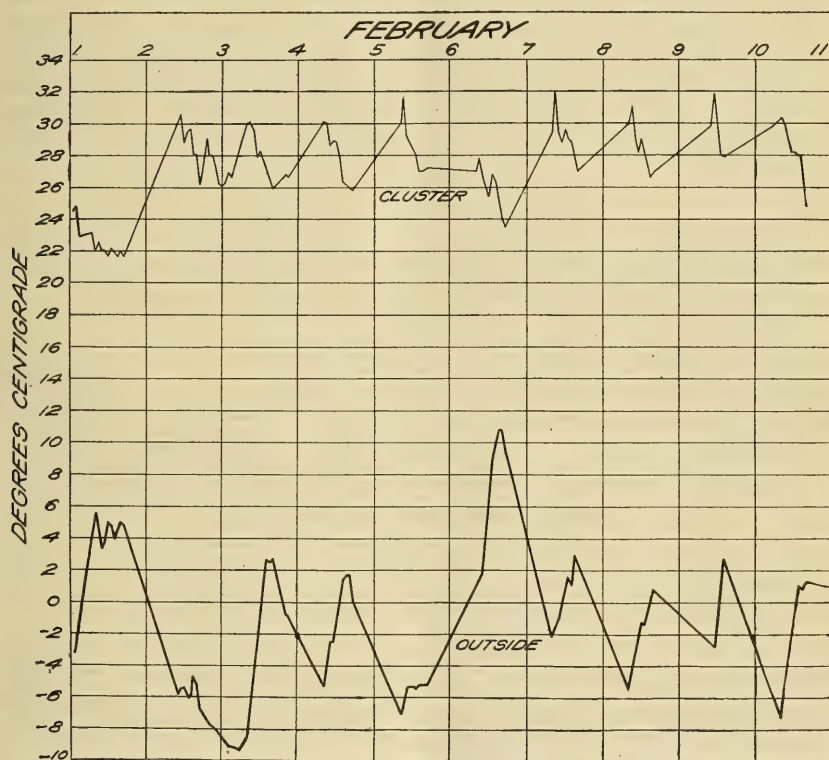


FIG. 8.—Curves showing relation of temperature of center of bee cluster to outer temperature, Feb. 1 to 10.

it would appear that the contraction of the entrance and the tight bottom board were not of much service in protecting the colony from cold. Colonies without bottom boards have frequently been known to survive extreme winter cold. It may be, however, an advantage to a colony to be protected from the sweep of violent winds; but there is no evidence that this colony appreciably warmed the lower part of the hive in which it was wintering. Under such conditions the bottom of the cluster is bathed in an atmosphere of the same temperature as the outside.

COMPARISONS OF TEMPERATURES OF THE CENTER OF THE CLUSTER AND OF THE OUTSIDE AIR.

The curves have revealed no more striking results than the relation observed between the temperature in the center of the cluster, c , as compared with the temperature of the outside air, o . These curves (fig. 8) at times show a peculiar inverse relation; for instance, when the thermometer out of doors registered low, below zero, the thermometer in the center of the cluster registered high, and vice versa. It should be observed that the maximum within the cluster occurs practically simultaneously with the minimum outside, and vice versa. Even minor changes outside are accompanied by corresponding inverse fluctuations in the cluster. The responses of the cluster to the outside temperature were shown particularly by the thermometer which recorded the temperature of the center of the cluster, c .

Up to the day of the first egg laying in the spring, March 9, the general courses of c and o continued relatively constant. But with the commencement of egg laying c changed its trend. The temperature of the brood cluster then became more and more constant, as may be seen in the results of the summer observations.

At first glance these curves might be interpreted as independent of each other, that the outside atmosphere has no effect on the center of the cluster, that it does not penetrate and modify the readings of c as it appears to have done in the case of the temperatures in the margin of the cluster. In all probability c more nearly represents the activities of the bees than do the other temperatures; but there is a relation of c to o . It might be supposed that the reaction registered by c is deferred for a period of hours and consequently appears at a time when o has changed. For instance, corresponding to the minimum of o on the 4th of February, the minimum of c came nine hours later. If this is due to a delay or "lag," maxima and minima in some cases are delayed for 24 hours or more. But this can not be; there are many minor variations which appear on the curves, and which are synchronous. Were there no relation of c to o these minor variations would either not have appeared in c , or, more especially, they would not have occurred simultaneously with a minor fluctuation in the outside temperature. It is therefore impossible to explain the phenomena on the ground of retardation (lag), for in that case it would be far more constant than is evident.

Related to the assumed explanation by delay or "lag," humidity or condensation, convection, radiation, and conduction might be assumed to be factors involved. The experimental colony furnishes no data for a consideration of humidity or condensation. The factors of convection, radiation, and conduction can not be conceived as slow enough to retard c from 9 to 24 hours nor would it account for its minor,

synchronous variation. Without doubt of these three factors the loss of heat from the cluster by convection is sufficient to counteract the hypothesis of the lag. Coupled with this the other factors would be expected to participate. The convection is also modified by the generally known contraction and relaxation of the cluster, referred to elsewhere.

These physical phenomena are evidently unsatisfactory as an interpretation from this standpoint of the lag. Thorough comparison of the charts fails to provide suitable material for conclusions as to the cause.

Table III shows the relative increase of temperature in the cluster corresponding to the progress of the winter season, while Table IV shows the monthly maximum and minimum temperature of the center of the cluster during the period from November 9 to March 9.

TABLE III.—*Relative increase of temperature in the bee cluster corresponding to the progress of the winter season.*

Month.	Range of temperature.	
	° C.	° F.
November, beginning of winter conditions.....	20 to 24	68.0 to 75.2
December.....	20 to 22	68.0 to 71.6
Jan. 1 to 18.....	22 to 25	71.6 to 77.0
Jan. 19 to 31.....	23 to 28	73.4 to 82.4
February.....	24 to 30	75.2 to 86.0
Mar. 1 to 9.....	27 to 32	80.6 to 89.6
When brood rearing is established.....	34 to 35	93.2 to 95.0

TABLE IV.—*Monthly maximum and minimum temperature of the center of the bee cluster during the winter period, Nov. 9 to Mar. 9.*

Month.	Temperature of cluster.	
	Maximum.	Minimum.
November.....	27° C. 80.60° F.	17° to 18.2° C. 62.60° to 64.76° F.
December.....	18.5° and 31.3° C. ¹ 65.30° and 88.34° F.	18.1° C. 64.58° F.
January.....	30.2° C. ² 86.36° F.	19° C. 66.20° F.
February.....	32° C. ³ 89.60° F.	21° C. 69.80° F.
Mar. 1-9.....	33.2° C. ⁴ 91.76° F.	27° C. 80.60° F.

¹ On a very warm day, Dec. 28.

² This occurred on two occasions, Jan. 14 and 30, at 8 a. m., when the outside temperature was 4° C. or more below freezing.

³ Approximated several times when outside temperature was below freezing.

⁴ Occurred after a warm day; approaches summer conditions

EFFECTS OF MANIPULATION ON THE CLUSTER.

Good beekeepers know that it is not well to open a hive in winter, but perhaps few realize the resulting effects on the colony. In Washington there are days in every winter month which are sufficiently warm to permit opening a hive without chilling the bees. It was necessary, partially in order to observe the effects on the

colony and partially to know their condition, to open the hive under experimentation. The results recorded by the thermometers on all of these occasions are pronounced. In the course of the observations on this colony it was found impossible to disturb the colony in the slightest degree, even to remove and replace a thermometer, to jar the colony, or to puff smoke in at the entrance, without noticeably affecting the temperature. These effects, as in the case of opening the hive, were not always temporary, but sometimes lasted for hours. Any disturbance resulted in an almost immediate rise in the temperature, and was appreciable throughout the cluster.

On March 12 the colony was opened for 15 minutes at 1 o'clock in the afternoon. The thermometers throughout the hive and even the one below the frames to some extent registered an immediate rise in temperature. When the hive was closed the cluster was soon reestablished but it was several hours before the temperature in the margins of the cluster became normal. On the interior of the cluster, however, the excitement and its effects were not so soon overcome. The curve for *c* shows that not until the next day did conditions approximate normal; the effects were appreciable even the day following the opening of the hive.

These results agree with the experience of many practical beekeepers, who consider it unadvisable to open their hives during the winter.

BEHAVIOR OF THE CLUSTER IN WINTER: OBSERVATIONS ON THE CHECK COLONY.

By means of the check colony with glass top and bottom, described on pages 5-6, it was possible to watch the movements of the bees throughout the winter at any time of day or night.

Various theories have been advanced by beekeepers to account for the behavior of bees in winter, but the writer is not aware that they are based on continuous and close observation. For instance, it has been maintained by some that bees semihibernate; by others it is affirmed that there is at intervals a general warming up of the colony in order that it may feed. The theory is that at stated periods bees generate enough heat to enable them to brave the cold and to expand the cluster sufficiently to enable them to reach fresh stores. It is not necessary to multiply theories on the condition and activities of bees in winter.

In a previous portion of the text the relation of the temperatures of the cluster to the temperature of the outside air has been sufficiently considered. It remains now to describe the activity of the bees as seen in the glass check hive. In some respects the movements or the reaction of the bees, and more particularly of the cluster as a whole, to the stimuli of changes in the atmospheric conditions was rather pronounced.

In watching this colony it was found that the density, and consequently the shape of the cluster, varied from day to day. When the air outdoors was warm, the cluster expanded; with cold, it contracted. The expansion usually did not cause the bees to cover more frames, but caused them to cover more completely those frames which they were occupying. Thus the expansion was usually downward toward the bottoms of the frames and in the direction of the entrance. With cold, the bees receded from the bottoms of the frames and from the top bars.

At all times the colony was sensitive to the slightest jar. The bees were also especially sensitive to the light which burst in upon them whenever the covering of the glass top was removed. If the hand were passed over the glass, bees would fly toward it as if to sting. This was noticed no matter how cold the day and shows that the colony, and particularly the outside of the cluster, is far from torpid, inactive, or semiquiescent. At practically all times there were bees moving on the outside of the cluster or on the top bars of the frames. Whenever the hive warmed up in the sun, although there were no bees flying, this was evident. There can be no question, therefore, of the alertness and activity of a colony in winter.

One of the most surprising observations was the apparent interchange of bees from the inside of the cluster with those on the outside of the cluster. As the writer watched the cluster, the head of a bee would gradually appear from below the bees forming the shell of the cluster. Finally this bee emerged and took her place with the others on the outside. Similarly, bees were frequently seen to disappear into the mass. The behavior was in no way general, but apparently was going on constantly and gradually. The phenomenon was repeatedly observed under all manner of conditions and at different times of day and night. By carefully arranging the covers, so that it was unnecessary to remove them, and thus cause a jar, it was proven that this behavior is normal and not the result of a disturbance of the bees. It must be concluded, therefore, that in this way the same bees may not be exposed to the outside cold for a long period. So long as they are able to keep up their own body temperature they remain outside, but when chilled they pass into the interior. Thus there must be a continual interchange of bees from the outside to the inside. Were it possible of observation, there would doubtless be found a relation of the interchange to the meteorological conditions. In cold weather the interchange may be expected to be greater.

In severe weather the bees were especially compact and their arrangement definite and constant. They were arranged side by side between the tops of the frames, with their heads downward. At the lower part of the cluster they were also arranged head down but with a little less regularity. It is difficult to see just what this means.

As further evidence that the colony is not torpid in cold weather, some of the other activities observed will be of interest. During the day, particularly, the bees were seen grooming and combing one another, feeding, and fanning at the outside of the cluster; and when the light was admitted to the top, they sometimes flew up as if to sting. It should also be stated that on nights of the most severe weather the bees in both this check colony and in the experimental colony were heard faintly and intermittently buzzing. This buzzing was even more noticeable on cold nights than on warmer ones. A peculiar trembling of the bee such as is seen in summer was not infrequently noticed. All of these activities are commonly observed in summer, but heretofore have not been thought to occur in winter and spring before the colony is able to fly forth.

It is probable that the heat of the sun has no slight influence on the cluster. At least in the check colony under observation it was evident that the cluster sought the sunny side of the hive, the front above the entrance, where from 10 or 11 o'clock in the morning until sundown the sun shone on the hive.

TEMPERATURE ACCOMPANYING THE LAYING OF THE FIRST EGGS.

With the laying of the first eggs in the spring, which marks the beginning of summer activity, striking changes occur in the behavior and temperature of the cluster. The central thermometers *b* and *c* were particularly affected. Upon opening the hive March 12 eggs less than three days old were discovered. Up to March 9 *c* had usually continued its winter course inversely to *o*, as is described and illustrated above by figure 8. But after March 9, when the first eggs were seen, the course of *c* changed and the inverse relationship was no longer apparent.

In order to explain the change in the course of *c* in relation to *o*, the behavior of the bees at egg-laying time must be considered. During the winter, while fresh air is necessary, there is no such need of it as when the eggs, or more particularly the brood, appear. Moreover, for incubation and for brood rearing a much higher and more constant temperature is needed. The effects of drops in the temperature of the outside air must be overcome. In preparing room for the laying of the queen, the zone for the brood nest is established, which is an important factor in the change in the course of curve *c*. All of these things appear immediately in the curve at the time of incubation. Formerly, when the bees went forth on a warm day there was a drop in *c*; now the trend of *c* is slightly upward during the warmth of the day corresponding somewhat with the warmth outside. Flight occurs nearly every day.

It is the belief of many beekeepers who winter their bees in cellars that too high a temperature is likely to cause uneasiness and brood

rearing. Root (1908) calls attention to the necessity of maintaining a temperature of not more than 45° F. (7.22° C.) at the approach of spring. The writer is not aware that any systematic study of the temperatures of bees in cellars has ever been made, so that it is impossible to say how the temperature of the cluster would compare with that of the colony under experimentation. The prevailing outside temperature, however, in the present experiment was found to be about 45° F. (7.22° C.) for several days previous to the laying of the first eggs, March 9.

At any rate in this experiment it appears that a temperature of 45° F. (7.22 C.), with an occasional maximum outer temperature of 8° to 11° C., is closely associated with the beginning of egg laying. But there are probably other factors of importance, particularly the matter of food. In establishing the experimental colony late in the fall, it was impossible for the bees to store any pollen. In the spring, however, for a week previous to egg laying they were seen gathering it. This might be expected to be an important stimulus to egg laying, and the bees could not rear brood until some could be gathered. While there appears to be a close relation between stimuli, temperature out of doors, and pollen gathering to the laying of eggs, details of the phenomena can be worked out only on a larger number of colonies under experimental conditions.

Another noticeable phenomenon which occurred at this time was the equalization of the temperature throughout the cluster. This might occur earlier in colonies protected from the winds and in sunny locations and later in colonies less favorably situated. If, however, upon experimentation this should be found to be one of the fundamental stimuli to egg laying, it would in a measure explain the fact that eggs do not always appear at the same time in all of the colonies of a bee yard. Another factor would be the strength of the colony and the resulting heat which it could produce and conserve. These results of the present investigation suggest great possibilities for discovering the stimuli which regulate the beginning of egg laying in the spring and which might influence the periodicity of brood rearing during the summer.

So far the consideration has been largely of the period in which eggs were laid and which preceded directly the beginning of incubation or brood rearing. It will be seen, therefore, that this time is in a sense transitional from the winter condition to the summer season, the topic which will next be considered.

TRANSITION FROM WINTER TO SUMMER CONDITIONS.

The phenomena mentioned in the preceding caption which accompanied the laying of the first eggs marked the beginning of the transition from winter to summer conditions, but this transition was not

completed until brood rearing was well established. With the establishment of brood rearing, the changes which manifested themselves with the first eggs became intensified. The course of the temperature recorded at *c* became unlike that which was observed in the winter and was influenced more directly by the outside temperature. The influence of the outside temperature became less and less marked, as is shown from the fact that the oscillation of *c* became less and less, the temperature in the center of the cluster became more constant, and the temperature throughout the hive became more equalized. As was stated, the turning point came on the 9th of March, but it was a little more than two weeks, about the 24th or 25th of March, before the colony really assumed normal summer temperature condition. Once this was gained, the temperature, particularly of the center of the cluster, remained relatively constant until fall. This transition period of two weeks was characterized by several features.

There was an increase of temperature both in the colony and out of doors. Out of doors the maximum ranged between 12° and 18° C. (53.6° to 64.4° F.), but even more favorable weather followed the establishment of brood rearing and the maximum ranged from 18° to 25° C. (64.4° to 73.4° F.). To a certain extent the temperature of the colony was raised like that of the outside temperature. The increase was general throughout the colony and must be attributed to the need of more heat for brood rearing, more ventilation, and the general increased activity of the bees. At this time *b* and *c* ranged constantly between 33° and 35° C. (91.4° to 95° F.), which will be seen to be practically the range throughout the summer.

In a word, the transition from winter to summer conditions was accomplished in a surprisingly short time. Accompanying incubation and brood rearing the temperature was gradually raised and became equalized through the hive, and once well established was maintained during the summer. Although the transition was relatively abrupt, it would be expected to vary with the colony and perhaps be prolonged in unfavorable weather.

GENERAL PHENOMENA OF THE SUMMER TEMPERATURE.

The constancy and equalization of the temperature and the range of 33° to 35° C. (91.4° to 95° F.), which characterized the close of the transition from winter to summer conditions, characterize equally well the prevailing summer phenomena. So constant were the temperatures in summer that their peculiarities may be briefly summarized. Few external factors influenced the hive temperature, and these affected it but slightly. In the original plan of the experiment it was hoped that it would be possible to discover whether there is any correlation between honey flows and temperatures; but inasmuch as the season was excessively dry and the flowers secreted no nectar

for weeks at a time, this phase of the experiment could not be carried out.

RELATION OF *c* TO THE OUTSIDE TEMPERATURE.

Whatever is said of *c* in the following paragraphs applies equally to *b*, and practically as well to all the thermometers in the hive.

Although the temperature at *c* coursed constantly in the opposite direction to *o* during the winter, there is no appreciable correlation between the temperatures in the summer. It might be said of the hive that the temperature as a whole was independent of external conditions. A few exceptions to this will follow, however. During a period of stormy and cooler weather, for instance, although there were slight changes which will be discussed later, the temperatures were largely unaffected. Moreover, since the oscillation of *c* was slight, as will be explained, there was little relationship between the temperature of the center of the cluster and *o*.

THE MAXIMA AND MINIMA OF *c* IN RELATION TO *o*.

The daily oscillation between the maximum and minimum of *c* was usually less than 1°C . (1.8°F .), and in many instances it was but one or two tenths of a degree. On the whole the temperature in the brood nest is remarkably constant, ranging between 34° and 35°C . (93.2° to 95°F .).

Even with this slight fluctuation there was perceptible on many days a maximum and minimum for *c*, and particularly for the other hive thermometers which perhaps were the most influenced by external conditions. It may be said that, roughly, the maxima and minima occurred within two hours of the maxima and minima of *o*, but since in some instances this happened previous to the maximum and minimum out of doors, the warming up of the colony due to the increasing activity of the bees must have had its effect.

To show how closely the maxima of the thermometers in the outer parts of the cluster ultimately approached the readings of the central thermometers, it may be said that while in April the maximum of the outer thermometers in the hive was 19°C . (66.2°F .), in the following months it rarely fell below 34°C . (93.2°F .). In September, however, with the general cooling of the atmosphere, it fell to 28°C . (82.4°F .). This showed the tendency at the close of the experiment for the colony to approach winter conditions. The facts show again the unity or equalization of the temperature throughout the cluster, which in the brood-rearing season ranges between 34° and 35°C . (93.2° to 95°F .). The maxima and minima are shown in Table V. The range of the oscillation shows the constancy of the temperature during the height of the season and the greater fluctuations in spring and fall.

TABLE V.—*Maximum and minimum temperatures of the center of the cluster during summer. Thermometer C.*

Month.	Maximum.		Minimum.		Approximate range.	
	° C.	° F.	° C.	° F.	° C.	° F.
April.....	35.4	95.7	31.6	88.9	4	7.2
May.....	36.0	96.8	33.8	92.9	2	3.6
June.....	35.5	95.9	33.6	92.5	2	3.6
July.....	35.0	95.0	33.2	91.8	2	3.6
August.....	35.8	96.4	33.8	92.9	2	3.6
September.....	34.8	94.6	28.0	82.4	7	12.6

FLUCTUATIONS IN THE HIVE TEMPERATURE AND THE CAUSES.

It has already been said that the fluctuations in the hive temperature were slight and that hot days and winds had very slight effect on the cluster temperature. There are some minor fluctuations due to internal and external disturbances which caused decrease or increase in the hive temperature.

THE EFFECT OF "ORIENTATION" OR "PLAY FLIGHTS."

Every beekeeper is familiar with the "play flights" of young bees about noon on warm sunny days. These are generally believed to be "orientation flights," in which the young bees fly forth in circles and with head toward the hive in order to learn its location. During the period of resumed brood rearing in August these flights occurred every few days in the experimental colony. At such times thermometer readings were taken at short intervals. Instead of causing the heat of the hive to increase these flights first caused a decrease, then a slight increase. Table VI presents figures for a typical observation, made after the bees had been confined to the hive by inclement weather for three days.

TABLE VI.—*Effects of "orientation flights" of bees on the temperature of the hive.*

Aug. 28.	Thermometer.													
	a.		b.		c.		d.		e.		f.		o.	
	° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.
6 a. m. ¹	34.0	93.2	34.4	93.92	34.4	93.92	34.4	93.92	33.6	92.48	34.6	94.28	15.6	60.08
7 a. m.....	34.0	93.2	34.4	93.92	34.4	93.92	34.0	93.2	33.4	92.12	34.4	93.92	16.4	61.52
8 a. m. ²	34.0	93.2	34.2	93.56	34.2	93.56	34.0	93.2	33.4	92.12	34.6	94.28	16.8	62.24
9 a. m.....	34.0	93.2	34.0	93.2	34.3	93.74	34.0	93.2	33.2	91.76	34.6	94.28	17.4	63.32
10 a. m.....	34.0	93.2	34.2	93.56	34.3	93.74	34.0	93.2	33.2	91.76	34.8	94.64	18.0	64.40
11 a. m. ³	33.8	92.84	33.8	92.84	33.8	92.84	33.8	92.84	33.2	91.76	34.2	93.56	19.4	66.92
11.30 a. m. ⁴	33.8	92.84	34.0	93.2	34.0	93.2	34.0	93.2	33.8	92.84	34.4	93.92	20.0	68.0
12 m.....	34.0	93.2	34.0	93.2	34.0	93.2	34.0	93.2	33.6	92.48	34.4	93.92	19.6	67.28
1 p. m.....	34.0	93.2	34.2	93.56	34.2	93.56	34.0	93.2	33.6	92.48	34.8	94.64	20.2	68.36
2 p. m. ⁵	33.8	92.84	34.0	93.2	34.0	93.2	33.8	92.84	33.6	92.48	34.4	93.92	20.2	68.36
2.15 p. m.....	34.0	93.2	34.0	93.2	34.0	93.2	34.0	93.2	33.6	92.48	34.4	93.92	20.4	68.72
2.30 p. m. ⁶	34.0	93.2	34.0	93.2	34.2	93.56	34.0	93.2	33.6	92.48	34.6	94.28	20.0	68.0
2.45 p. m.....	34.0	93.2	34.2	93.56	34.2	93.56	34.0	93.2	33.8	92.84	34.8	94.64	20.4	68.72
3 p. m.....	34.0	93.2	34.2	93.56	34.2	93.56	34.0	93.2	33.8	92.84	34.8	94.64	20.8	69.44
4 p. m.....	34.0	93.2	34.4	93.92	34.4	93.92	34.2	93.56	33.8	92.84	34.8	94.64	20.2	68.36

¹ Cloudy.² Bees fly slightly.³ First good fly for three days.⁴ Quieted flight.⁵ Bees fly freely again.⁶ Quiet again.

It will be noticed that short flights were taken at 8 o'clock in the morning when the thermometer *c* fell 0.2° C. At 11 o'clock the first flight of importance occurred. Then there was another slight drop in the temperature followed by a rise. At 2 o'clock there was a similar flight and change in the thermometer. In all cases within 15 to 30 minutes the thermometer had regained its normal temperature. While the drop was actually slight, when it is remembered that the daily fluctuation in the temperature was frequently but a fraction of a degree, the decrease was relatively considerable. The same effect was noticed in the spring and in the early part of the season, when the bees first commenced to take field trips. This cooling effect must be attributed to the rushing forth of the bees from the cluster; in so doing they liberate the confined heat of the cluster. Another factor is probably the excessive fanning at the entrance which usually accompanies these "play" flights. When the activities wane and the bees commence to return to the hive, the temperature resumes its normal condition.

A similar decrease in temperature was common in the early morning when the bees commenced to leave the hive for the field. For comparison with the foregoing, the readings taken in the early morning of August 3 and 4 are presented in Table VII.

TABLE VII.—*Effects of early morning flight of bees on temperature of the hive.*

Date.	Thermometer.											
	<i>a</i>		<i>b</i>		<i>c</i>		<i>d</i>		<i>e</i>		<i>o</i>	
<i>Aug. 3.</i>	$^{\circ}$ C.	$^{\circ}$ F.	$^{\circ}$ C.	$^{\circ}$ F.	$^{\circ}$ C.	$^{\circ}$ F.	$^{\circ}$ C.	$^{\circ}$ F.	$^{\circ}$ C.	$^{\circ}$ F.	$^{\circ}$ C.	$^{\circ}$ F.
8 a. m.	34.0	93.2	34.2	93.56	34.6	94.28	34.2	93.56	34.0	93.2	22.6	72.68
9 a. m.	33.8	92.84	34.2	93.56	34.4	93.92	34.2	93.56	33.8	92.84	26.0	78.80
10 a. m.	33.9	93.02	34.4	93.92	34.8	94.64	34.2	93.56	34.0	93.2	26.8	80.24
11 a. m.	34.0	93.2	34.4	93.92	34.8	94.64	34.6	94.28	34.0	93.2	27.4	81.32
12 m.	34.0	93.2	34.6	94.28	34.8	94.64	34.6	94.28	34.0	93.2	28.0	82.40
<i>Aug. 4.</i>												
5 a. m. ¹	34.4	93.92	34.6	94.28	34.8	94.64	34.6	94.28	34.2	93.56	21.2	70.16
6 a. m.	34.4	93.92	34.6	94.28	34.6	94.28	34.6	94.28	34.4	93.92	21.0	69.80
7 a. m. ²	34.0	93.2	34.4	93.92	34.6	94.28	34.2	93.56	34.0	93.2	22.6	72.68
8 a. m.	34.0	93.2	34.4	93.92	34.8	94.64	34.4	93.92	34.0	93.2	25.0	77.00
9 a. m.	34.0	93.2	34.8	94.64	34.8	94.64	34.4	93.92	34.0	93.2	27.0	80.60

¹ Fanning entrance.² Bees begin to fly freely.

EFFECTS OF CLUSTER HEAT ON THE TEMPERATURE BELOW THE FRAMES.

It was found that the heat from the cluster had no perceptible influence on the temperature of the air below the frames during the winter. Practically the air was at the outside temperature. But in summer totally different conditions prevail; the temperature within the hive becomes equalized. Furthermore, the crowding of the bees at certain seasons tends to force them to hang down from the bot-

toms of the frames or even out at the entrance. Consequently that space which was outside the frames assumes cluster conditions.

Early in the season *f* averaged 3° C. higher than *o* at all times; at the end of the season, September, it averaged from 5° to 6° C. higher. By the middle of May *f* stood only 1° or 2° C. lower than the thermometers in the cluster, although the thermometer in the outside air was much lower. Throughout the summer there was practically no difference between *c* and *f*. During the storm period, as will be seen in Table IX, which is discussed farther on, *f* ranged even higher than the prevailing cluster temperature. This was undoubtedly due to the massing of the bees below the frames as they were crowded in from the alighting board.

THE EFFECTS OF STORM.

Since the summer of 1908 was remarkably dry and free from storms, it is not possible to draw any definite conclusions upon the effects of storms, cold waves, and winds upon the cluster temperature. The only severe storm of the summer occurred in the latter part of August. The outside thermometer went as low as 14° C. (57.2° F.), while before and after this period there were frequent readings ranging from 20° to 30° C. (68° to 86° F.). During the storm there were several high winds. These, however, did not blow directly in at the entrance. The bees were thus confined for three days, and at times showed much evidence of shifting and massing at different parts of the hive. In a glass observatory hive the bees were actually seen to cluster now in one part of the hive and then in another. The wind and rain also drove the bees in off of the alighting board and forced them to hang from the bottoms of the frames. If the readings of the thermometers nearest the outside of the hive are rightly interpreted, the cluster withdrew from the walls of the hive, and this caused a decrease in the temperature at these points. While there is some evidence in the figures that the cold outside the hive had its effects on the center of the cluster, the temperature was not permitted to remain below 34° C. (93.2° F.). No fall was recorded lower than 33.8° C. (92.84° F.). Thus the bees appear to be able to control and conserve the temperature with remarkable constancy, even though there be high wind and relatively low temperature. Table IX, in comparison with the figures for a bright day in Table VIII, reveal these facts.

TABLE VIII.—*Temperatures of a bee colony on a normal day.*

Time.		Thermometer.											
Month and day.	Hour.	a.		b.		c.		d.		e.		o.	
		°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.
Aug. 15	6 a. m. ¹	34.4	93.92	34.4	93.92	35.0	95.00	34.8	94.64	34.8	94.64	24.4	75.92
	7 a. m.	34.4	93.92	34.4	93.92	34.8	94.64	34.8	94.64	34.6	94.28	26.0	78.80
	8 a. m.	34.2	93.56	34.4	93.92	34.8	94.64	34.8	94.64	34.8	94.64	24.6	76.28
	9 a. m. ²	34.2	93.56	34.4	93.92	34.8	94.64	34.8	94.64	34.8	94.64	25.8	78.44
	10 a. m.	34.6	94.28	34.6	94.28	34.8	94.64	34.6	94.28	34.6	94.28	27.6	81.68
	11 a. m.	34.8	94.64	34.8	94.64	35.0	95.00	35.0	95.00	35.0	95.00	28.8	83.84
	12 m.	34.8	94.64	34.8	94.64	35.0	95.00	35.0	95.00	35.0	95.00	29.0	84.20
	1 p. m.	34.8	94.64	35.0	95.00	35.0	95.00	35.0	95.00	35.0	95.00	29.6	85.28
	2 p. m.	35.0	95.00	35.0	95.00	35.0	95.00	35.2	95.36	35.2	95.36	30.4	86.72
	4 p. m.	35.0	95.00	35.0	95.00	35.0	95.00	35.2	95.36	35.2	95.36	29.2	84.56
	6 p. m.	35.0	95.00	35.0	95.00	35.2	95.36	35.2	95.36	35.2	95.36	28.2	82.76
	7 p. m.	34.8	94.64	34.8	94.64	35.0	95.00	35.2	95.36	35.0	95.00	27.6	81.68
Aug. 18	8 p. m.	35.0	95.00	35.0	95.00	35.0	95.00	35.0	95.00	35.0	95.00	26.6	79.88
	6 a. m.	34.0	93.2	34.2	93.56	34.0	93.2	34.0	93.2	34.2	93.56	21.8	71.24
	7 a. m. ³	34.2	93.56	34.2	93.56	34.4	93.92	34.4	93.92	34.2	93.56	22.0	71.60
	8 a. m.	34.2	93.56	34.2	93.56	34.4	93.92	34.4	93.92	34.2	93.56	22.4	72.32
	9 a. m. ⁴	34.4	93.92	34.4	93.92	34.6	94.28	34.6	94.28	34.4	93.92	25.0	77.00
	10 a. m. ⁵	34.4	93.92	34.6	94.28	34.6	94.28	34.8	94.64	34.6	94.28	26.0	78.80
	11 a. m.	34.6	94.28	34.8	94.64	34.8	94.64	34.8	94.64	34.8	94.64	26.5	79.70
	12 m.	34.8	94.64	34.8	94.64	35.0	95.00	35.0	95.00	35.0	95.00	27.4	81.32
	1 p. m.	34.8	94.64	34.8	94.64	35.0	95.00	35.0	95.00	35.0	95.00	28.4	83.48
	2 p. m.	34.8	94.64	34.8	94.64	35.0	95.00	35.0	95.00	35.0	95.00	29.0	84.20
	3 p. m.	34.8	94.64	34.8	94.64	35.0	95.00	35.0	95.00	35.0	95.00	28.0	82.40
	4 p. m.	34.8	94.64	34.8	94.64	35.0	95.00	35.2	95.36	35.2	95.36	28.0	82.40
	6 p. m.	34.8	94.64	34.8	94.64	35.0	95.00	35.0	95.00	35.2	95.36	27.4	81.32
	7 p. m.	34.8	94.64	34.8	94.64	35.0	95.00	35.0	95.00	35.0	95.00	26.2	79.60
	8 p. m.	34.8	94.64	34.8	94.64	35.0	95.00	35.0	95.00	35.0	95.00	25.6	78.08

¹ Cloudy and calm.² Clearing, calm and close.³ Cloudy.⁴ Clearing and calm.⁵ Clear.TABLE IX.—*The effects of storm and wind on the temperatures of the bee colony.*

Time.		Thermometer.													
		a.		b.		c.		d.		e.		f.		o.	
Month and day.	Hour.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.
Aug. 25	8 a. m. ¹	34.2	93.56	34.4	93.92	34.2	93.56	34.2	93.56	34.0	93.20	34.6	94.28	20.4	68.72
	8.30 a. m.	34.2	93.56	34.2	93.56	34.2	93.56	34.2	93.56	34.0	93.20	34.6	94.28	19.8	67.64
	9 a. m. ²	34.4	93.92	34.4	93.92	34.2	93.56	34.2	93.56	33.8	92.84	34.6	94.28	19.8	67.64
	10 a. m.	34.0	93.20	34.2	93.56	34.2	93.56	34.2	93.56	34.0	93.20	34.6	94.28	20.8	69.44
	11 a. m. ³	34.2	93.56	34.4	93.92	34.4	93.92	34.2	93.56	34.0	93.20	34.6	94.28	20.2	68.36
	12 m.	34.0	93.20	34.8	94.64	24.2	93.56	34.4	93.92	34.0	93.20	34.6	94.28	20.6	69.08
	1 p. m. ⁴	34.2	93.56	34.4	93.92	34.2	93.56	34.2	93.56	34.0	93.20	34.6	94.28	18.4	65.12
	2 p. m.	34.0	93.20	34.6	94.28	34.0	93.20	34.0	93.20	34.4	93.92	34.6	94.28	17.8	64.04
	3 p. m.	34.0	93.20	34.4	93.92	34.2	93.56	34.2	93.56	34.0	93.20	34.6	94.28	17.6	63.68
	4 p. m.	34.0	93.20	34.8	94.64	34.2	93.56	34.0	93.20	34.0	93.20	34.6	94.28	17.0	62.60
	5 p. m.	34.0	93.20	34.0	93.20	34.2	93.56	34.0	93.20	34.0	93.20	34.6	94.28	16.2	61.16
	6 p. m. ⁴	34.0	93.20	34.2	93.56	34.0	93.20	34.0	93.20	33.6	92.48	34.6	94.28	18.2	64.76
Aug. 26	7 p. m.	34.0	93.20	34.4	93.92	34.2	93.56	34.2	93.56	33.6	92.48	34.6	94.28	16.4	61.52
	8 p. m.	33.8	92.84	34.2	93.56	34.2	93.56	34.0	93.20	33.4	92.12	34.6	94.28	16.2	61.16
	9 p. m.	34.0	93.20	34.2	93.56	34.2	93.56	34.0	93.20	33.6	92.48	34.6	94.28	15.0	59.00
	10 p. m.	34.0	93.20	34.4	93.92	34.4	93.92	34.4	93.92	33.0	91.40	34.6	94.28	15.0	59.00
	11 p. m.	34.0	93.20	34.2	93.56	34.4	93.92	34.2	93.56	33.2	91.76	34.6	94.28	14.6	58.28
	12 p. m.	33.8	92.84	34.0	93.20	34.2	93.56	34.0	93.20	33.4	92.12	34.6	94.28	15.4	59.72
	1 a. m.	33.8	92.84	34.2	93.56	34.0	93.20	34.0	93.20	33.4	92.12	34.6	94.28	15.6	60.08
	2 a. m.	33.6	92.48	34.0	93.20	34.0	93.20	34.2	93.56	33.0	91.40	34.6	94.28	14.8	58.64
	3 a. m. ⁵	33.6	92.48	34.2	93.56	34.2	93.56	34.0	93.20	33.4	92.12	34.6	94.28	17.4	63.32
	4 a. m. ⁶	33.6	92.48	34.2	93.56	34.2	93.56	34.0	93.20	33.4	92.12	34.6	94.28	16.2	61.16
	5 a. m. ⁶	33.6	92.48	34.0	93.20	34.2	93.56	34.0	93.20	33.2	91.76	34.6	94.28	17.0	62.60
	6 a. m. ⁶	33.6	92.48	34.2	93.56	34.2	93.56	34.0	93.20	33.2	91.76	34.6	94.28	16.6	61.88
7 a. m. ⁶	33.6	92.48	34.4	93.92	34.2	93.56	33.6	92.48	33.4	92.12	34.6	94.28	17.0	62.60	

¹ Cloudy.² Breeze from north.³ Raining a little.⁴ Rain.⁵ High wind from east.⁶ High wind from east, no rain.

Another fact to which reference has been made under the caption, "Effects of cluster heat on the temperature below the frames," should be mentioned here. During this period of storm, *f* frequently recorded a higher temperature than the thermometers above it. This was undoubtedly due to the crowding of the bees in off of the alighting board, forming a curtain below the frames. This is an advantage in helping to conserve the heat and in preventing the cold, inward draft through the entrance from striking directly on the brood.

THE EFFECTS OF TRANSPORTATION ON THE TEMPERATURE OF THE COLONY.

Not infrequently beekeepers sustain heavy losses in moving their bees, although it is not usually done in extremely hot weather. Since the moving of the experimental colony to College Park, Md., a distance of about 11 miles, was unavoidable, the writer decided to make the most of the necessity and determine in so far as possible the effects of transportation on the colony. Even with precautions, strong and populous colonies sometimes smother. Brood is often killed, supposedly from excessive heat. With these points in mind every precaution was taken to protect the colony from harm; and since no damage resulted, the experiment reveals the temperature conditions in a successful transportation of a strong colony under most adverse circumstances—extreme heat and humidity and bad roads.

The trip was commenced at 10.30 a. m. on July 2. The day was humid, with intermittent sunshine and clouds, and no breeze. In Washington the mercury rose to 32.33° C. (90° F.) at 2 o'clock. The road was through the city of Washington over asphalt and stone pavements for several miles and then over rough country roads, which had scarcely any shade. The colony was moved on a spring express wagon with cover, the curtains of which were kept down on the sunny side so as to prevent the sun from striking directly on the hive. The other curtains were rolled up in order to allow all the ventilation possible, but since there was no breeze all the draft which the bees got must have been procured by fanning and by the movement of the wagon.

The colony was crowded into a 10-frame Langstroth hive and the entrance was screened the night previous. All of the thermometers remained in position. This, of course, prevented giving ventilation through the top of the hive, which is the common practice in moving bees. In order to give room for expansion of the cluster and to confine the air as little as possible, the hive was set over an empty body, on the bottom of which wire cloth was tacked. In order to allow the air to circulate freely beneath the hive, it was supported above the

bottom of the wagon on $\frac{7}{8}$ -inch strips of wood, the spring of which relieved to some extent the jolt of the wagon. In the morning, before the colony was disturbed and just after it was loaded, thermometer readings were taken. On the road readings were also made at short intervals. In this way the result of every successive event in the trip was known.

The first disturbance, carrying the hive downstairs and loading, was immediately responded to by the bees. The first 15 minutes on the road were but slightly more disturbing. Gradually, however, the temperature increased until 1.30 o'clock in the afternoon and an hour previous to releasing, when practically the maximum was reached, 36.0°C . (96.8°F .). It should be mentioned, however, that during the next few hours and even after the bees had their liberty the thermometers in the distant parts of the hive, *a* and *e*, registered 36.2°C . (97.16°F .). But it is probable that the bees clustered more densely at these points than they did in the center of the hive. This temperature can not be considered particularly abnormal, although it is higher than any temperature registered immediately before or after the transportation. On several occasions during the summer and even in May, practically the same degree was reached; but since in normal circumstances it never went higher than 36°C . (96.8°F .), the temperature observed is probably nearly as high as can be reached by bees without damage. It would not have taken many degrees more than this to have softened the combs and to have caused them to sag and break. The melting point of pure wax is 62° to 64°C . (143° to 145°F .), but the difference between the melting point and the point at which combs become soft enough to sag must be considerable, perhaps 20°C . (36°F .).

It can not be said that the temperature was higher at any one part of the hive than at another, unless possibly there was a slight tendency for the brood cluster to be maintained cooler. This would naturally be expected, but under such trying circumstances the phenomenon could not be measured satisfactorily. At no time on the trip did the bees hang down from their combs into the lower body, and upon releasing them there was no evidence of condensation. At all times, as would have been expected, there was considerable fanning. Furthermore, the bees were not made cross by their confinement, as was the case when the rest of the colonies of the apiary were moved, which was done under much more favorable circumstances except for ventilation. That no brood died in the experimental colony is further evidence that 36°C . (96.8°F .) is not abnormal.

The colony was placed in its new position at 2.30 o'clock and the bees liberated. The effects of their liberty on the temperatures were not apparent, however, as will be seen in Table XI, for more than an

hour, when the temperatures began gradually to fall. Finally, when the bees had orientated themselves and had commenced to return to the hive, there was a noticeable quieting and a perceptible drop in the mercury. At 7.30 o'clock, after all the bees had returned to the hive, conditions were practically normal.

In conclusion it may be said that the conditions under which the bees were moved, although trying and about as adverse as possibly could be encountered, did not produce abnormal heat in the hive. The temperature increased only 2°, from 34° to 36°+C. (93.2 to 96.8° F.). While it is generally admitted that ventilation from the top is preferable in moving bees, on the hypothesis that warm air rises, ventilation from the bottom was a success in the case under discussion. In moving the rest of the department apiary to College Park earlier in the season, when the weather was more favorable, the day being cloudy with showers, three colonies suffered severely from overheating and condensation. These colonies were screened at the entrance and over the top of the hive; but apparently the screening of the top was not sufficient, because when the bees became excited and expanded as a result of the heat, they packed so tightly against the top screen as to shut out all ventilation. The tendency of bees is upward and toward the light. On the contrary, if ventilation is given from below, there is less tendency for them to pack against the screen. While it is generally maintained that for moving colonies top ventilation is preferable, the present experiment would indicate that bottom ventilation is practical and advantageous.

For comparison, figures taken the day previous (Table X) and the day after the transportation (Table XII), as well as on that day (Table XI), are presented.

TABLE X.—*Readings of thermometers, July 1, on day previous to transportation of bee colony.*

Hour.	Thermometer.											
	a.		b.		c.		d.		e.		o.	
	° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.	° C.	° F.
9 a. m.	33.4	92.12	34.0	93.20	34.0	93.20	33.8	92.84	33.8	92.84	25.8	78.44
10 a. m.	33.6	92.48	34.0	93.20	34.2	93.56	33.6	92.48	33.6	92.48	27.0	80.60
11 a. m.	33.8	92.84	34.2	93.56	34.2	93.56	33.8	92.84	33.6	92.48	28.5	83.30
12 m.	33.9	93.02	34.5	94.10	34.5	94.10	33.9	93.02	33.9	93.02	29.0	84.20
1 p. m.	34.0	93.20	34.5	94.10	34.5	94.10	34.0	93.20	34.0	93.20	29.8	85.64
2 p. m.	34.4	93.92	34.8	94.64	34.8	94.64	34.0	93.20	34.0	93.20	31.5	88.70
3 p. m.	34.4	93.92	34.8	94.64	34.8	94.64	34.0	93.20	34.0	93.20	31.5	88.70
4 p. m.	34.6	94.28	34.8	94.64	34.8	94.64	34.2	93.56	34.2	93.56	32.2	89.96
8 p. m.	34.8	94.64	34.8	94.64	35.0	95.00	34.8	94.64	35.0	95.00	29.0	84.20

TABLE XI.—*Readings of thermometers during transportation of bees, July 2. Day extremely warm and sultry.*

Hour.	Thermometer.										Observations.		
	<i>a</i>		<i>b</i>		<i>c</i>		<i>d</i>		<i>e</i>				
	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.			
9 a. m.	34.4	93.92	34.4	93.92	34.4	93.92	34.0	93.20	34.0	93.20	Hive closed but un- moved.		
10.15 a. m.	35.0	95.00	35.0	95.00	35.0	95.00	34.8	94.64	34.8	94.64	Hive loaded on wagon.		
10.30 a. m.	35.0	95.00	35.0	95.00	35.0	95.00	34.8	94.64	34.8	94.64	Drive to College Park started.		
10.45 a. m.	35.2	95.36	35.0	95.00	35.1	95.18	34.9	94.82	35.0	95.00	Sun and clouds.		
11 a. m.	35.4	95.72	35.2	95.36	35.2	95.36	35.0	95.00	35.0	95.00		Do.	
11.15 a. m.	35.4	95.72	35.0	95.00	35.1	95.18	35.0	95.00	35.0	95.00		Do.	
11.30 a. m.	35.6	96.08	35.2	95.36	35.2	95.36	35.0	95.00	35.0	95.00		Do.	
11.45 a. m.	35.8	96.44	35.4	95.72	35.6	96.08	35.1	95.18	35.2	95.36	Do.		
12 m.	35.8	96.44	35.6	96.08	35.6	96.08	35.3	95.54	35.4	95.72	Do.		
12.15 p. m.	35.8	96.44	35.8	96.44	35.6	96.08	35.4	95.72	35.6	96.08	Stopped 30 minutes for lunch.		
12.45 p. m.	35.8	96.44	35.6	96.08	35.6	96.08	35.4	95.72	35.6	96.08	Hive set on stand and opened.		
1 p. m.	35.8	96.44	35.6	96.08	35.6	96.08	35.6	96.08	35.6	96.08		Bees all returned to hive.	
1.15 p. m.	36.0	96.80	35.8	96.44	35.8	96.44	35.8	96.44	35.8	96.44			Quiet and normal.
1.30 p. m.	36.0	96.80	36.0	96.80	35.9	96.62	35.8	96.44	36.0	96.80			
2 p. m.	36.0	96.80	36.0	96.80	36.0	96.80	35.9	96.62	36.0	96.80	Quiet and normal.		
2.30 p. m.	36.2	97.16	36.0	96.80	36.0	96.80	36.0	96.80	36.1	96.98		Quiet and normal.	
3 p. m.	36.2	97.16	36.0	96.80	36.0	96.80	36.0	96.80	36.2	97.16			Quiet and normal.
3.30 p. m.	36.2	97.16	35.8	96.44	35.8	96.44	36.0	96.80	36.0	96.80			
4 p. m.	36.1	96.98	35.4	95.72	35.8	96.44	36.0	96.80	36.0	96.80	Quiet and normal.		
4.30 p. m.	35.4	95.72	34.1	93.38	34.8	94.64	35.1	95.18	35.4	95.72		Quiet and normal.	
5 p. m.	35.0	95.00	34.0	93.20	34.6	94.28	34.9	94.82	35.0	95.00			Quiet and normal.
6.30 p. m.	34.6	94.28	34.2	93.56	34.2	93.56	34.4	93.92	34.4	93.92			
7 p. m.	34.4	93.92	34.2	93.56	34.2	93.56	34.2	93.56	34.2	93.56	Quiet and normal.		
7.30 p. m.	34.4	93.92	34.0	93.20	34.0	93.20	34.2	93.56	34.2	93.56		Quiet and normal.	
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TABLE XII.—*Readings of thermometers, July 3. Day after transportation of bees.*

Hour.	Thermometer.										Observations.
	<i>a</i>		<i>b</i>		<i>c</i>		<i>d</i>		<i>e</i>		
	° <i>C</i> .	° <i>F</i> .	° <i>C</i> .	° <i>F</i> .	° <i>C</i> .	° <i>F</i> .	° <i>C</i> .	° <i>F</i> .	° <i>C</i> .	° <i>F</i> .	
7.30 a. m. . . .	33.8	92.84	34.0	93.20	34.0	93.20	33.6	92.48	33.0	91.40	Cloudy. Breeze.
8.30 a. m. . . .	33.8	92.84	33.8	92.84	34.0	93.20	33.4	92.12	33.0	91.40	
10 a. m.	33.8	92.84	34.0	93.20	34.0	93.20	33.4	92.12	33.6	92.48	
11 a. m.	34.0	93.20	34.0	93.20	34.0	93.20	33.4	92.12	33.4	92.12	
12 m.	34.0	93.20	34.2	93.56	34.2	93.56	33.6	92.48	33.4	92.12	Bees returned.
7 p. m.	34.8	94.64	34.8	94.64	34.6	94.28	34.2	93.56	34.0	93.20	
8 p. m.	34.8	94.64	34.6	94.28	34.6	94.28	34.0	93.20	34.0	93.20	



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(PROFESSIONAL PAPER.)

IDENTIFICATION OF COMMERCIAL FERTILIZER MATERIALS.

By WILLIAM H. FRY, *Scientist in Soil Laboratory Investigations.*

INTRODUCTION.

In working with commercial fertilizers it is often desirable to know not only the percentages of the various ingredients as given by chemical analysis but also the compounds in which these occur in the fertilizer, i. e., the carriers of these ingredients. The calculation of the rational composition from the ultimate analysis in the case of salts gives results which are open to doubt and requires a much more complete analysis than is usually made. In the case of organic materials such a calculation is practically impossible. It, therefore, becomes necessary to identify a great number of the substances occurring in commercial fertilizers by means which give the compounds as distinguished from the chemical ingredients of these compounds.

The following substances were chosen for examination:

Potassium chloride.
Potassium sulphate.
Ammonium sulphate.
Kainite.
Sodium nitrate.
Superphosphate.
Calcium nitrate.
Lime.
Apatite.
Phosphate rock.
Gypsum.
Limestone.
Calcium cyanamid.

Basic slag.
Ground rocks and minerals.
Cottonseed meal.
Raw bone meal.
Steamed bone meal.
Peat, humus, muck, etc.
Dried blood.
Slaughterhouse tankage.
Garbage tankage.
Fish scrap.
Dissolved bone black.
Shells.

NOTE.—This bulletin gives methods for identifying the carriers of the various fertilizing ingredients, and is intended to serve as a laboratory guide to those studying this phase of the fertilizer question.

It was found that potassium chloride, potassium sulphate, ammonium sulphate, kainite, sodium nitrate, calcium nitrate, apatite, gypsum, limestone, and other ground rocks and minerals could be identified definitely by microscopic-petrographic methods. For the equipment and *modus operandi* of determining substances by their optical characters reference is made to the literature of the subject.¹ A brief outline only is here given.

EQUIPMENT.

For the determination of the optical constants of the various salts and consequently for the identification of the salts themselves, a petrographical microscope is practically a necessity. Ordinary microscopes converted into petrographic microscopes by the addition of various adjuncts are clumsy at best and are far from being satisfactory. Petrographic microscopes, as at present manufactured, have reached a high degree of perfection and, considering the quality of the workmanship and their all-round usefulness, the price is not exorbitant. For a full description of these instruments, reference is made to the trade catalogues. A few words concerning them, however, are necessary in order to render intelligible the description of the manipulations used in determining the optic constants.

The petrographic microscope is, in general make-up, similar to ordinary microscopes. It has both coarse and fine adjustments for focusing; the stage is constructed so as to revolve around the axis of the instrument and is graduated into 360° , so that the angle of any revolution may be read off directly. Just below the stage is a condenser lens so fitted that it may be readily thrown in or out at pleasure. Below the condenser lens is a nicol prism which acts as a polarizer, and below the polarizer is the mirror. The objectives are attached to the tube of the microscope by a clamp device which admits of their ready insertion or removal. The objective is centered by two screws acting at right angles to each other. In the tube of the microscope is another nicol prism, the analyzer, which may be thrown in or out of the line of vision and which may be rotated from a position parallel to the polarizer to a position at right angles to it. Between the objective and the analyzer is a slit at an angle of 45° to the planes of the nicols through which various adjuncts are inserted as needed. Above the analyzer is another slit through which another accessory, Bertrand lens, is inserted as needed. The oculars have cross hairs at right angles to each other and parallel to the planes of the nicols.

¹ Bul. 91, Bureau of Soils, U. S. Dept. Agr. Iddings, Rock Minerals. Johannsen, Determination of Rock-Forming Minerals. Rosenbusch and Wülfing, *Mikroskopische Physiographie der petrographisch wichtigen Mineralien*, 2 vols.

The accessories are a quartz wedge, a quarter undulation mica plate, a gypsum plate, a Bertrand lens, a Bertrand ocular, an eyepiece micrometer, mainly, with others, a description of which, with their uses, will be found in the standard texts.

In examining substances with a view to obtaining their optical constants a series of oils of definite refractive indices are used as embedding mediums. Johannsen¹ gives the following series, which contains oils suitable for practically all purposes:

Refractive indices of various liquids used as embedding mediums.

Liquid.	Index.	Liquid.	Index.
Carbon bisulphide.....	1.768	Ethylene bromide.....	1.536
Iodo methylene.....	1.740	Monochlor benzene.....	1.527
α -Monobrom naphthalene.....	1.658	Cedar oil.....	1.516
α -Monochlor naphthalene.....	1.639	Benzene.....	1.501
Mono-iodo benzene.....	1.621	Xylene.....	1.495
Cassia oil at 21°.....	1.606	Beechnut oil.....	1.477
Cinnamon oil.....	1.605	Almond oil.....	1.469
Bromoform.....	1.588	Carbon tetrachloride.....	1.466
Monobrom benzene.....	1.561	Glycerine.....	1.460
Nitrobenzene.....	1.554	Amyl alcohol.....	1.4075
Clove oil.....	1.544		

Various mixtures of almond oil and cassia oil can be made with refractive indices running from 1.474 to 1.562.

The indices of these liquids vary somewhat on standing, and they should be checked up to at least the second decimal place at occasional periods. Any good refractometer will serve the purpose, or mineral grains of known refractive indices may be used as will be presently explained.

The substance to be examined is mounted on a slide in one of the oils, preferably one of medium index, and covered with a cover glass. It is then ready for observation. If the indices of the liquid and the substance are fairly different the outlines of the particles show up distinctly, and the crystal habit, cleavage angles, color, and so forth, should be noted. Crystallographic and cleavage angles may be approximately measured by aid of the cross hairs and the rotating stage. Efforts should be made to determine whether the color of colored grains is that of the substance itself or of inclusions. High-power lenses will usually accomplish this. However, the majority of the salts are colorless, and consequently color is only rarely of importance. These preliminary observations made, the optic properties of the substance are determined as outlined below.

ISOTROPIC SUBSTANCES.

All substances are either amorphous or crystalline; and all crystalline substances are either isotropic or anisotropic, i. e., they transmit light with equal velocity in all directions or they transmit light with

¹ Rock-Forming Minerals in Thin Sections, pp. 16-18 (1908).

different velocity in different directions. Amorphous substances and substances crystallizing in the isometric system are isotropic. All others are anisotropic. Whether a given substance is isotropic or anisotropic can be readily determined by crossing the nicols; that is, by putting the analyzer in at right angles to the polarizer, and rotating the stage. Isotropic substances remain dark during a complete rotation, whereas anisotropic substances alternately light up and become dark four times during a complete rotation. It should be noted here that sections of anisotropic uniaxial substances cut at right angles to the principal axis remain dark during rotation; but this case can be easily determined by means of interference figures, as will be seen later. Should the substance be isotropic, there remains only the refractive index to be determined.

REFRACTIVE INDEX.

By focusing sharply on an edge of the grain, analyzer out, and then raising the tube of the microscope slightly by means of the fine adjustment, a line of light will be seen to move into or out of the grain. If the refractive index of the grain is higher than that of the oil, the line will move in; if the index of the oil is the higher, the line will move out. In other words, the line of light moves into the medium of higher index on raising the tube. The reverse phenomena takes place on lowering the tube. Another method is to use an objective of medium power with the condenser in and raised. A shadow is thrown across half the field by placing the finger between the reflecting mirror and the polarizer. The grains with an index higher than that of the oil appear dark with a bright band on the side toward the shadow. Should the index of the oil be higher, the bright band is on the side from the shadow. It being known whether the index of the grain or of the oil is the higher, by trial an oil can be found in which the substance completely disappears. The indices of the grain and of the oil are then the same; and since the index of the oil is known, the index of the substance is also known. As a supplementary test, a shadow can be again thrown across the field. Then, the indices of the substance and of the oil being the same, one side of the grain is colored blue and the other red. The isotropic nature of the substance in conjunction with the index of refraction is sufficient to identify it.

ANISOTROPIC SUBSTANCES.

Should the substance be anisotropic, the extinction angles are first measured. This is done by noting the position of the grain when it is completely dark and then rotating it until a crystallographic or a cleavage face is parallel to one of the cross hairs. The angle of rotation read off from the stage is the angle of extinction. A more exact method is that of the Bertrand ocular. This ocular consists of two

right and two left handed quartzes of the same thickness cut perpendicular to the axis. The lines of contact between the four parts are parallel to the principal sections of the nicols. This ocular is inserted in the tube of the microscope in place of the ordinary ocular and a cap nicol placed over it in such a position as to cross the polarizer. The analyzer is out. When a double refracting substance is placed under the microscope with this arrangement, the adjacent quadrants appear dissimilarly colored and the diagonal quadrants similarly colored. Upon rotating the stage a position is reached at which the four quadrants are uniformly colored. Then the principal sections of the grain are parallel to those of the nicols. The angles can be read off as above. In tetragonal, hexagonal, and orthorhombic substances the extinction is always parallel to a crystallographic direction, and consequently the angle of extinction is zero. In monoclinic substances the extinction is parallel or symmetrical only in the zone parallel to the *b*-axis. The extinction is oblique in all other sections. In triclinic substances the extinction directions are all inclined.

PLEOCHROISM.

Some anisotropic substances possess the property of changing their color or the intensity of their color when rotated under the microscope with the analyzer out. This phenomenon is due to different degrees of absorption in different directions in the crystal. For example, in one direction one color constituent of white light may be absorbed more than another color. The degree of absorption in one direction is expressed as greater, less, or equal to the degree of absorption in another direction; and the absorption axes are assumed to coincide with the axes of vibration of the light.

REFRACTIVE INDICES.

Anisotropic substances belonging to the tetragonal and hexagonal systems have two indices of refraction; and those belonging to the orthorhombic, monoclinic, and triclinic systems have three. These indices may be determined substantially as given for the indices of isotropic substances. One index may be observed in one position of the crystal. The stage is then rotated and another index determined. Except in cases of strongly double refracting substances, the determination of the mean index is sufficient for practical purposes.

BIREFRINGENCE.

When the refractive indices are known accurately, the maximum birefringence is obtained directly from them by subtracting the lowest index from the highest. Since, however, it is not always practicable to determine the indices with the required degree of accuracy, other methods are used. The table of Michel-Lévy is here very useful. A copy of it will be found in most textbooks of optical

mineralogy. In its use it is necessary to know the thickness of the grain. To determine this a sharp focus is first made with the fine adjustment of the microscope on the upper surface of the grain and then on the lower surface. The fine adjustment of course must be first calibrated. The value thus obtained is multiplied by the refractive index of the substance, which gives the real thickness. The thickness line is then followed across the table to the color given by the grain between crossed nicols. The nearest oblique line is then followed to the edge of the table, where the birefringence will be found. It should be remembered that this table gives only the maximum birefringence, and consequently it is necessary to try several orientations of the grain in order to be sure that the birefringence obtained is the maximum. Other more elaborate methods for determining birefringence will be found in the standard texts.

OPTICAL CHARACTER OF ELONGATION.

To determine this, the grain is first rotated to extinction between crossed nicols. It is then rotated 45° , thus bringing the interference color to a maximum. For thin plates or weakly refracting crystals a mica plate, for thick sections or strongly refracting crystals a gypsum plate, or quartz wedge, is inserted between the crossed nicols. The vibration directions of these plates must, of course, be known. The colors of the grain will rise to higher orders when similar axes in the grain and plate have the same direction, and will fall when different axes are superimposed. Knowing the directions of vibration in the plate, the directions of vibration in the grain are also known. When the direction of elongation of the crystal is practically the same with the axis of least ease of vibration, the grain has positive elongation. When the direction of elongation of the crystal is practically the same as the axis of greatest ease of vibration, the grain has negative elongation.

UNIAXIAL SUBSTANCES.

All anisotropic substances may be divided, by means of interference figures, into two great classes, uniaxial and biaxial substances. Interference figures are obtained, with good illumination, by using a high-power objective, putting in and raising the condenser lens, crossing the nicols, and removing the ocular. The figure is rendered more distinct by placing over the top of the microscope tube a small blackened disk with a very small aperture through its center. Thus practically all light except that coming from the grain under examination is excluded from the range of vision. The figure may also be seen enlarged by leaving the ocular in and placing a Bertrand lens between it and the analyzer. In the case of uniaxial crystals lying perpendicular to the optic axis, the figure has the form of a dark cross, generally with colored rings around the intersection of the arms of the

cross. When the crystal is so oriented that the section viewed is perfectly perpendicular to the optic axis the center of the cross remains stationary during a complete rotation of the stage. Should the section be slightly inclined, the center will revolve around the intersection of the cross hairs. It may happen that the section is so much inclined that the center of the cross does not appear in the field at all. In this case, a dark bar is seen moving across the field, as the stage is rotated, occupying successive positions parallel one to another and the principal sections of the nicols, followed on further rotation of the stage by a bar perpendicular to the first and also occupying successive parallel positions. In cases where the section viewed is parallel to the optic axis, hyperbolæ are shown which are somewhat similar to those of biaxial figures. However, they do not appear until the stage is nearly in the 90° position. Then they move in, form an indistinct cross, and move out again very rapidly. The hyperbolæ leave the field in the direction of the principal axis.

OPTICAL CHARACTER.

The optical character of uniaxial substances, that is, whether they are optically positive or negative, may be determined by means of the quarter undulation mica plate, the gypsum plate giving red of the first order, quartz or mica wedge, etc. In general the quartz or mica wedge or plate serve the purpose when the center of the interference figure is seen in the field. The interference figure is first obtained and then one of these accessories placed between the objective and the analyzer in the 45° position. In optically positive crystals the colored rings in the NE. and SW. quadrants contract while those in the NW. and SE. quadrants expand. With negative crystals the reverse takes place. It is of course necessary to know the directions of vibration of the plates used. This can always be determined by the same means as those given for crystals by using the plate as an object to be examined. Should the center of the cross be beyond the field of the microscope, a gypsum plate giving red of the first order with the α direction parallel to the elongation of the plate is used. Positive crystals show blue in the NE. and SW. quadrants and yellow in the NW. and SE. quadrants. The phenomena are reversed in the case of negative crystals.

BIAxIAL SUBSTANCES.

Biaxial interference figures in sections lying perpendicular to the acute bisectrix, Bx_a , provided the axial angle is less than the field of the microscope, show, when the plane of the axes and the cross hairs coincide, a black cross and a series of colored curves. The points of emergence of the optic axes are indicated by dark spots with colored lemniscates surrounding them and joining at

the center. Upon rotating the stage, the cross dissolves into two hyperbolæ. The convex sides of the hyperbolæ are always toward the acute bisectrix. The smaller the axial angle, the nearer together are the loci of the optic axes; and finally, for very small angles, the interference figure approaches the form of a uniaxial interference figure. When the axial angle is so large that neither of the loci of the optic axes show, the biaxial character is indicated by the movement of the bars.

Sections lying perpendicular to the obtuse bisectrix, Bx_o , show similar figures to those of sections lying perpendicular to the acute bisectrix, provided the axial angle is not too large.

Should the section be inclined to the bisectrix, one of the dark spots may be completely outside of the field of the microscope. The other spot, however, will show, and this is sufficient to determine the biaxial character.

Sections at right angles to an optic axis show a single straight dark bar surrounded by almost circular concentric curves whenever the bar is parallel to the principal planes of the nicols. This bar changes to a hyperbola on rotating the stage, and the convex side is toward the acute bisectrix.

In sections parallel to the plane of the optic axes the interference figure is similar to that of uniaxial crystals parallel to the optic axis. In this case it is advisable to apply a slight pressure with the finger upon one side of the cover glass which causes the crystal to move about into some other orientation which will show one of the interference figures described above.

OPTICAL CHARACTER.

The optical character of biaxial crystals may be determined by means of the mica plate, gypsum plate, and quartz or mica wedge. To use the mica plate, the interference figure is first obtained and the stage rotated until the hyperbolæ form a cross. Upon the insertion of the quarter undulation mica plate, the phenomena are then the same as in uniaxial substances.

Sections perpendicular to the acute bisectrix, the interference figure of which shows no colored curves, are rotated until the hyperbolæ form a cross. The gypsum plate is inserted; and, if its α direction is parallel to the elongation of the plate, the center of the field is red and the NE. and SW. quadrants are colored blue while the NW. and SE. quadrants are yellow in positive crystals. The reverse phenomena take place in negative crystals.

If the stage is so rotated that the hyperbolæ form a cross, the phenomena presented on the insertion of a quartz or mica wedge are similar to those of a uniaxial crystal. By remembering that the convex sides of the hyperbolæ are always toward the acute bisectrix,

the optical character of a biaxial crystal can be determined when only one hyperbola appears in the field. The phenomena are similar to those presented when both hyperbolæ appear.

OPTIC AXIAL ANGLES.

In the interference figure of sections cut normal to the acute bisectrix and rotated into the 45° position, the distance between the hyperbolæ, i. e., between the two dark spots, represents the angle between the two optic axes. The observed angle, $2E$, however, is not identical with the actual angle, $2V$. The symbol $2H$ is sometimes used to represent the angle when it is measured in an oil. The distance between the points of emergence of the axes, in the 45° position, can be measured by a micrometer eyepiece. Let this distance be $2d$. Then

$$\sin E = \frac{d}{C}.$$

E is half the axial angle in air, d is half the distance between the points of emergence of the optic axes as measured with the eyepiece micrometer, and C is a constant which must be determined for each lens combination. It may be determined by using a mica plate, whose axial angle is known, as an object and substituting in the formula. If n is the mean index of refraction of the mineral, then

$$\sin V = \frac{\sin E}{n}.$$

$2V$ can thus be readily found. In a large number of cases the simple designation of the angle as "large" or "small" will serve all purposes; and this relative size may be observed by a glance at the interference figure.

DISPERSION.

Here ρ is used to indicate red light, and ν violet light. Observations are made on the interference figures.

In the orthorhombic system the dispersion is least, $\rho < \nu$ or $\rho > \nu$, for the color within the circle which is nearest the bisectrix and which touches the concave side of the hyperbola when the crystal is in the 45° position. The colors are symmetrical to the bisectrix.

In the monoclinic system there are three kinds of dispersion, inclined, horizontal, and crossed. In inclined dispersion the colors are arranged symmetrically to the line joining the loci of the hyperbolæ, but are not symmetrical in the other direction. One locus is oval shaped, larger, and less intense; and the other is round, intense, and smaller. In horizontal dispersion, the colors are not arranged symmetrically to the line joining the loci of the hyperbolæ. They are symmetrical, however, to a line at right angles to this line. In crossed dispersion there is only a point of symmetry.

In the triclinic system the arrangement of colors in the interference figure is unsymmetrical.

In actual determinative work it will seldom be found necessary to determine all of the foregoing optical properties of crystals. But in doubtful cases, the more data available the better; and even in seemingly clear cut cases it is sometimes advisable to make as thorough a study of the substance as possible. The methods described herein are, in general, those of the simplest and most accessible nature, but with their aid and a little practice anyone should soon be able to determine many of the materials ordinarily used in the manufacture of fertilizers. However, it should be remarked that problems continually arise for the solution of which wide experience and a comprehensive knowledge of all theoretical questions involved are none too much.

OPTICAL CONSTANTS OF FERTILIZER MATERIALS.

The diagnostic optical constants of the substances mentioned on page 2 were taken mainly from Dana and Groth¹ and are as follows:

Potassium chloride. Sylvite. KCl.—Isometric. Habit cubic. Cleavage cubic perfect. Refractive index, 1.4903. Sometimes exhibits anomalous double refraction.

Potassium sulphate. Arcanite. K₂SO₄.—Orthorhombic.

Twinning yields pseudo-hexagonal forms.

Optically positive (+). Ax. pl. $\parallel$ a. B $\perp$ c.

Dispersion feeble, $\rho > \nu$ oil, $\rho < \nu$ in air.

Refractive indices, $\alpha = 1.4920$, $\beta = 1.4935$, $\gamma = 1.4970$.

$2V = 66^\circ 30'$, $2E = 109^\circ 57'$.

Ammonium sulphate. Mascagnite. (NH₄)₂SO₄.—Orthorhombic. Pseudo-hexagonal. Optically positive (+). Ax. pl. $\parallel$ b. Bx $\perp$ a. Dispersion weak, $\rho < \nu$. $2E = 87^\circ 44'$, $84^\circ 6'$. $2V = 52^\circ 12'$. Refractive indices, $\alpha = 1.5209$, $\beta = 1.5230$, $\gamma = 1.5330$.

Kainite. MgSO₄.KCl+3H₂O.—Monoclinic. Optically negative (-). Ax. pl. $\parallel$ b. Dispersion inclined, very distinct. $2V = 84^\circ 33'$. $2E = 141^\circ$ approx.

Sodium nitrate.—Rhombohedral. Uniaxial. Optically negative (-). Double refraction strong. Refractive indices for yellow, $\omega = 1.587$, $\varepsilon = 1.336$.

Calcium nitrate. Tetrahydrate. Ca(NO₃)₂.4H₂O. Monoclinic. Optically negative (-). Optic angle small. Double refraction high.

Apatite. (Ca(F,Cl)) Ca₄(PO₄)₃.—Hexagonal. Uniaxial. Optically negative (-). Double refraction weak. Refractive indices very close to 1.63.

¹Dana, System of Mineralogy. Groth, Chemische Kristallographie.

Gypsum. $\text{CaSO}_4 + 2\text{H}_2\text{O}$.—Monoclinic.

Optically positive (+). Plane of optic axes parallel to (010) at ordinary temperatures.

$\text{BxAc} = +52\frac{1}{2}^\circ$. Dispersion inclined strong.

$2V_Y = 58^\circ 8'$. $2E_r = 95^\circ 14'$, Refractive indices, $\alpha = 1.5205$, $\beta = 1.5226$, $\gamma = 1.5296$.

Limestone. Calcite. CaCO_3 .—Rhombohedral. Uniaxial. Optically negative (-). Double refraction strong. Refractive indices, $\omega = 1.658$, $\varepsilon = 1.486$. *Dolomite*, $(\text{Ca}, \text{Mg})\text{CO}_3$, is very similar; but the refractive index is greater, $\omega = 1.68$, $\varepsilon = 1.50$. Various chemical tests may be used to distinguish the two.¹

The mineralogical composition of ground rocks and ground minerals may be ascertained by petrographic methods. On account of the large number of minerals which might be present in such products, reference is here made to the literature already cited for their optical properties.

The above substances are readily differentiated under the microscope. Potassium chloride, being isometric, is isotropic, and consequently remains dark during a complete rotation of the microscope stage between crossed nicols. The refractive index serves as additional evidence and distinguishes this salt from halite (refractive index = 1.54) and other isotropic substances. The remaining substances are divided into two groups by means of interference figures. The rhombohedral and hexagonal substances give uniaxial figures; and the orthorhombic and monoclinic substances give biaxial figures. The uniaxial substances are sodium nitrate, apatite, calcite, and dolomite. All of them are optically negative, and consequently this characteristic does not aid in distinguishing them apart. The determination of the refractive indices, however, readily distinguishes them. The biaxial substances are potassium sulphate, ammonium sulphate, kainite, calcium nitrate, and gypsum. The optical character differentiates these into the optically positive group consisting of potassium sulphate, ammonium sulphate, and gypsum; and the optically negative group, kainite and calcium nitrate. In the former group potassium sulphate is immediately distinguished by its low index of refraction. Ammonium sulphate and gypsum may be distinguished by the other optic constants given. In the optically negative group kainite and calcium nitrate may be distinguished by the difference in size of the optic angle.

Phosphate rock can not be distinguished microscopically as such. But the mineralogic nature of the material, absence of other phosphatic material, and presence of water-insoluble phosphoric acid, jointly, are strong indications of it.

¹Iddings, *Rock Minerals*, p. 34.

Calcium cyanamid, according to L. Vuafart,¹ may be tested for as follows: "The presence of calcium cyanamid in a mixture containing other fertilizers can be detected by its odor, alkaline reaction, the large amount of calcium present, the black residue which is left after treating the sample with water, and the yellow precipitate obtained with silver nitrate which is insoluble in ammonium hydroxid but soluble in nitric acid. An impurity often present in the latter is a black acetylene silver insoluble in nitric acid. If organic fertilizers are present in the mixture, these can be detected by dissolving the cyanamid in hydrochloric acid, when the organic matter will remain behind as a black residue. Sulphuric acid added to such fertilizers will yield a brown solution."²

Basic slag contains a rather large amount of material attracted by an ordinary horseshoe magnet. The nonmagnetic material is transparent under the microscope, with a bluish color. It is anisotropic and biaxial. Tetracalcium phosphate is monoclinic and the double refraction is positive; but this can not always be seen in the commercial material. The refractive index of the transparent commercial material is very near 1.64. The biaxial nature and high index distinguished basic slag from any of the other substances treated of here.

Shells can be easily distinguished by their obvious shelly structure.

Cottonseed meal has a predominantly yellow color with brownish hull particles, and usually some cotton lint. Often it can be detected with the naked eye and is easily identified with the microscope.³

Raw bone meal is whitish in color. Mounted in oil, under the microscope, evident bone structure is seen.⁴

Steamed bone meal is very similar to raw bone meal, and it is not always possible absolutely to distinguish the two. The steamed bone may be somewhat darker in color, has a friable appearance, and does not show the sharp angles and edges seen in the raw product. An empyreumatic odor indicates the nature of the material.

Peat, humus, muck, etc., vary very much. The vegetable matter of the material, however, indicates its nature.

Dried blood, megascopically is blackish, dull dark red, and dark purplish in color. It is somewhat brittle. Microchemically blood may be tested for in numerous ways, e. g., the haemin test, guaiacum test, spectroscopic examination of the coloring matter, recognition of blood corpuscles, etc.⁵

¹ Ann. Falsif., 4 (1911), No. 32, pp. 321-324. Quotation and reference taken from Expt. Sta. Rec., 26, 564 (1912).

² A general discussion of cyanamid will be found in "Cyanamid," by E. J. Franke, Easton, Pa., 1913.

³ For details of cell structure and technique see Hanausek-Winton-Barber, The Microscopy of Technical Products, 1907.

⁴ Hanausek, loc. cit.

⁵ See Allen, Commercial Organic Analysis, Vol. IV, 1898.

Tankage is rather heterogeneous. Particles of bone and other animal matter are present. It has an empyreumatic odor.

Garbage tankage, on account of its extremely various and heterogeneous nature, can not be identified as a unit. Its heterogeneity, however, affords an indication of its nature.

Fish scrap has a characteristic odor. Flesh and bones are present. The general microscopic appearance of the material and its odor will usually serve to identify it.

Lime, both quick and slaked, can be easily identified chemically.

Superphosphate, in addition to water-soluble phosphoric acid and calcium sulphate, contains quartz and various other mineral particles. This can be best seen by leaching the material and studying the residue with the microscope.

Dissolved bone black contains much carbonaceous matter besides phosphoric acid, calcium sulphate, etc.

It thus appears that by far the larger number of the substances examined admit of positive identification. The exceptions are susceptible of such tests as will at least indicate their nature. There seems to be no doubt that by combining microscopic, petrographic, and chemical methods of examination reliable information can be gained as to the nature of the compounds constituting practically all fertilizers.

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(PROFESSIONAL PAPER.)

THE APPLICATION OF REFRIGERATION TO THE HANDLING OF MILK.

By JOHN T. BOWEN, *Technologist, Dairy Division.*

INTRODUCTION.

In the following pages an attempt has been made to discuss briefly the various applications of refrigeration, both when employing ice and refrigerating machinery, in the operation of the modern milk plant, creamery, or dairy, and to discuss in each instance the methods most commonly used in the latest and best equipped plants.

While refrigeration has made considerable advancement in dairying in the last few years, even more progress could have been made had more owners and operators of milk plants, creameries, and dairies been fully aware of the many advantages to be derived from the use of proper refrigeration. It is further believed that the manufacturers of refrigerating machinery are not familiar with the special conditions existing in this industry. Therefore the object of this bulletin is to be of service to the manufacturer of refrigerating machinery as well as to those employed in the dairy industry.

It is not intended to give in detail the size and arrangement of refrigerating equipment necessary in plants of various capacities, as the conditions vary to such an extent that to do so would be impossible, but to state briefly the elementary principles of refrigeration and refrigerating machinery and to describe what is recognized as the best and most modern practice in the industry and to leave the details in each case to those on the premises, who are better able to judge and to modify the suggestions given herein to suit the existing conditions.

It is a well-known fact that heat and cold perform very important duties in handling milk and milk products. In pasteurizing milk

NOTE.—Discusses the application of refrigeration in the operation of the modern milk plant and describes the various forms of mechanical and other systems of cooling. Of interest to producers, shippers, dealers, and consumers of milk generally, and also to manufacturers of refrigerating machinery and appliances.

heat is used to destroy the bacteria, or at least to reduce their number to such an extent as to prevent their producing disease; but pasteurized milk as well as unpasteurized market milk should be cooled to a temperature of 50° F. or below and held at this lower temperature until used. At a temperature below 50° F. bacteria multiply less rapidly, but between 50° and 100° F. the increase is very fast; hence the necessity for thorough cooling and the maintenance of low temperatures until used.

DEFINITIONS OF TERMS.

A knowledge of the terms used in refrigeration is necessary in order to better understand the matter given in the following pages. Therefore definitions of the principal terms and units employed are given for the benefit of those not already familiar with them.

British thermal unit.—A British thermal unit (B. T. U.) is the quantity of heat required to raise 1 pound of pure water 1 degree Fahrenheit, at or near its maximum density, 39.1° F. Some authorities consider a British thermal unit as the heat required to raise 1 pound of pure water from 61° to 62° F. For practical purposes, however, it may be considered the heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

Sensible heat.—Sensible heat is the heat that may be felt by the hand or measured by a thermometer.

Latent heat.—Latent or "hidden" heat is the heat which is expended in molecular work of separating the molecules of the substance and can not be measured by a thermometer. Every substance has a *latent heat of fusion*, required to convert it from a solid to a liquid, and another, *latent heat of vaporization*, required to convert it from a liquid to a gas or vapor. Thus, if heat is applied to a pound of ice at 32° F. it will begin to melt, and no matter how much heat is applied the ice will not get any hotter. After every particle of ice has melted, we will have 1 pound of water at 32° F., the same temperature as the ice before heat was applied. Experiments have shown that it requires 144 British thermal units to melt 1 pound of ice at 32° F. into water at 32° F.; hence the *latent heat of fusion* of ice is said to be 144.

If heat is applied to 1 pound of water at 212° F., the water will remain at 212° F. under atmospheric pressure until all of it has been evaporated into steam at 212° F. This has been found to require 970.4 British thermal units; hence the *latent heat of vaporization* of steam at atmospheric pressure is said to be 970.4 B. T. U.

Specific heat.—The specific heat of a substance may be defined as the ability of that substance to absorb heat compared to that of water. Water being one of the hardest of all substances to heat, its specific heat is taken at unity. Therefore the specific heat of other substances is usually less than unity. A better understanding of *latent* and *spe-*

cific heat may be had by studying the diagram in figure 9, on page 24, which shows graphically the relation of heat to temperature.

Ton refrigeration.—Refrigeration, or ice-melting capacity, is a term applied to represent the cold produced, and is measured by the latent heat of fusion of ice, which is 144 B. T. U. per pound. In other words, it is the heat required to melt 1 pound of ice at 32° F. into water at the same temperature. The capacity of a machine in tons of "ice melting" or "refrigeration" does not mean that the machine would make that amount of ice, but that the cold produced is equivalent to the melting of the weight of ice at 32° into water at the same temperature. Therefore 1-ton refrigeration is equal to $144 \times 2,000$, or 288,000 B. T. U. A 1-ton refrigerating machine is a machine that has a capacity sufficient to extract from an insulated bath of brine 200 B. T. U. per minute, 12,000 B. T. U. per hour, or 288,000 B. T. U. per 24 hours.

Absolute pressure.—Absolute pressure is pressure reckoned from a vacuum. Pressure gauges in general use are arranged to indicate pressure in pounds per square inch above atmospheric. To convert gauge pressure to absolute pressure, 14.7 pounds, the weight per square inch of air pressure at sea level, must be added.

CHANGES IN MILK CAUSED BY TEMPERATURE AND TIME.

PHYSICAL CHANGES IN MILK AT LOW TEMPERATURES.

During the last decade the progress made in the physical, chemical, and bacteriological studies of milk and its products has greatly modified the various dairy operations and has led to improved methods of treating and handling dairy products, based mainly on the application of the two extremes, heat and cold. The preservation of milk and its products depends almost entirely on the use made of these two factors. In this bulletin, however, we will discuss only the use of refrigeration as a means of preserving dairy products. Before discussing the practical application of refrigeration to the dairy industry it is advisable to make a short summary of the data at hand relating to the physical, chemical, and bacteriological changes and modifications which the action of cold produces in milk.

SPECIFIC HEAT.

In view of the wide variations in the specific heat of milk and cream, as found in the limited amount of literature on the subject, the United States Bureau of Standards was requested to make determinations of the specific heat of whole milk and single and double cream. Samples of milk and cream, approximating average conditions, were prepared by the Dairy Division laboratories and forwarded to the Bureau of Standards in the afternoon, placed in the calorimeter and packed

in ice until the next morning when observations were begun. The chemical analyses of the samples were as follows: $3\frac{1}{2}$ per cent milk: 12.68 per cent total solids, 9.18 per cent solids not fat, 87.32 per cent water; 20 per cent cream: 27.27 per cent total solids, 7.27 per cent solids not fat, 72.73 per cent water; 40 per cent cream: 44.30 per cent total solids, 4.30 per cent solids not fat, 55.70 per cent water.

In view of the fact that only a single test on one sample of the material was made the results can be considered only as tentative and not final.

TABLE I.—*Specific heat of milk and cream.*

Temperature.		Milk.	20 per cent cream.	40 per cent cream.	Temperature.		Milk.	20 per cent cream.	40 per cent cream.
° F.	° C.				° F.	° C.			
35.6	2.0		0.88		95.9	35.5	0.93	0.89	0.86
37.4	3.0	0.92		0.83	100.4	38.0			.80
43.7	6.5	.92	.91	.90	105.8	41.0	.92	.87	
48.2	9.0		.92		109.4	43.0			.78
51.8	11.0	.93		.96	114.8	46.0		.87	
55.4	13.0		.94		118.4	48.0	.92		.78
59.0	15.0	.94		1.02	123.8	51.0		.86	
66.2	19.0	.95	1.01	1.07	127.4	53.0			.77
71.6	22.0	.94	.95		131.0	55.0	.93	.86	
75.2	24.0			.93	136.4	58.0			.76
78.8	26.0	.93		.88	141.8	61.0	.93	.87	
82.4	28.0		.91		145.4	63.0			.72
86.0	30.0	.92		.88	150.8	66.0	.94		
89.6	32.0		.91						

The curves, figure 1, show the specific heat of $3\frac{1}{2}$ per cent milk and 20 and 40 per cent cream at different temperatures between 35.6° F. and 150.8° F.

COHESION AND VISCOSITY OF MILK.

Milk upon cooling assumes a denser semiliquid aspect and sticks more closely to the walls of the vessel than when warm. Consequently it is harder to clean, by means of water, a vessel that has contained cold milk than one that has contained warm milk. On the other hand, for the same reason, it is more difficult to cleanse vessels that have contained milk by the use of cold water than by the use of warm water. Milk is more liable to foam when cold than when hot, and the foam will keep longer. The foam, however, will disappear if the milk is heated. With the lowering of the temperature of milk the cohesion increases in proportion to its viscosity.

At 86° F. the viscosity is about 1.7 times as great in milk as it is in water, while at 32° F. its viscosity is about 2.4 times that of water. At 32° F. the viscosity of milk is about 2.6 times as great as it is at 86° F.

Freshly drawn milk shows a smaller viscosity than it does after being allowed to stand for some time. It is a well-known fact that the viscosity plays an important part in the formation of cream and in the skimming of milk.

COEFFICIENT OF EXPANSION OF MILK AND CREAM.

In Table II is given the change in the volume of milk and cream with varying percentages of fat and degrees of temperature. The

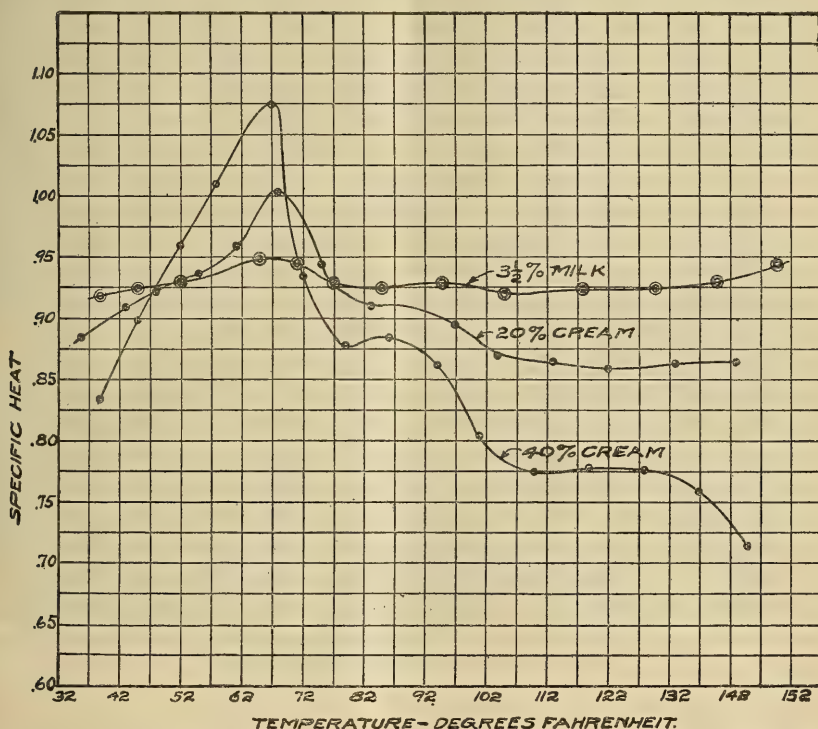


FIG. 1.—Curves showing the specific heat of milk, 20 per cent and 40 per cent cream at different temperatures.

percentage of fat varies in steps of 1 per cent from skimmed milk to double cream, and determination of change in volume has been made in steps of 2° F. from 50 to 140° F. A temperature of 68° F. (20° C.) has been taken as the basis and the change in volume reckoned from this temperature. These tentative determinations and those on specific gravity were made by the Division of Weights and Measures of the United States Bureau of Standards.

TABLE II.—*Volume¹ of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.).*

Per cent- age of but- ter- fat.	Temperature (° F.).											
	50	52	54	56	58	60	62	64	66	68	70	72
	Volume.											
0.025	0.9980	0.9980	0.9985	0.9985	0.9990	0.9990	0.9990	0.9995	0.9995	1.0000	1.0000	1.0005
1	.9980	.9980	.9985	.9985	.9990	.9990	.9990	.9995	.9995	1.0000	1.0000	1.0005
2	.9975	.9975	.9980	.9980	.9985	.9990	.9990	.9995	.9995	1.0000	1.0000	1.0005
3	.9975	.9975	.9980	.9980	.9985	.9990	.9990	.9995	.9995	1.0000	1.0000	1.0005
4	.9975	.9975	.9980	.9980	.9985	.9985	.9990	.9995	.9995	1.0000	1.0000	1.0005
5	.9975	.9975	.9980	.9980	.9985	.9985	.9990	.9995	.9995	1.0000	1.0000	1.0005
6	.9970	.9970	.9975	.9980	.9980	.9985	.9990	.9995	.9995	1.0000	1.0000	1.0005
7	.9970	.9970	.9975	.9975	.9980	.9985	.9985	.9990	.9995	1.0000	1.0000	1.0010
8	.9970	.9970	.9975	.9975	.9980	.9985	.9985	.9990	.9995	1.0000	1.0005	1.0010
9	.9965	.9965	.9970	.9975	.9980	.9985	.9985	.9990	.9995	1.0000	1.0005	1.0010
10	.9965	.9965	.9970	.9975	.9980	.9985	.9985	.9990	.9995	1.0000	1.0005	1.0010
11	.9965	.9965	.9970	.9975	.9980	.9985	.9985	.9990	.9995	1.0000	1.0005	1.0010
12	.9955	.9960	.9965	.9970	.9975	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
13	.9955	.9960	.9965	.9970	.9975	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
14	.9950	.9955	.9960	.9970	.9975	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
15	.9950	.9955	.9960	.9970	.9975	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
16	.9950	.9955	.9955	.9965	.9970	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
17	.9945	.9950	.9955	.9965	.9970	.9980	.9985	.9990	.9990	1.0000	1.0005	1.0010
18	.9940	.9945	.9950	.9960	.9970	.9980	.9980	.9985	.9990	1.0000	1.0005	1.0010
19	.9940	.9945	.9950	.9960	.9970	.9975	.9980	.9985	.9990	1.0000	1.0005	1.0010
20	.9930	.9940	.9945	.9955	.9965	.9975	.9980	.9985	.9990	1.0000	1.0005	1.0010
21	.9930	.9940	.9945	.9955	.9965	.9975	.9980	.9985	.9990	1.0000	1.0005	1.0010
22	.9930	.9940	.9945	.9955	.9965	.9975	.9980	.9985	.9990	1.0000	1.0010	1.0015
23	.9930	.9940	.9940	.9955	.9965	.9975	.9980	.9985	.9990	1.0000	1.0010	1.0015
24	.9925	.9930	.9940	.9950	.9960	.9975	.9975	.9985	.9990	1.0000	1.0010	1.0015
25	.9925	.9930	.9940	.9950	.9960	.9970	.9975	.9985	.9990	1.0000	1.0010	1.0015
26	.9925	.9930	.9940	.9950	.9960	.9970	.9975	.9985	.9990	1.0000	1.0010	1.0015
27	.9925	.9930	.9940	.9950	.9960	.9970	.9975	.9985	.9990	1.0000	1.0010	1.0015
28	.9915	.9925	.9935	.9945	.9955	.9965	.9975	.9980	.9990	1.0000	1.0010	1.0015
29	.9915	.9925	.9935	.9945	.9955	.9965	.9975	.9980	.9990	1.0000	1.0010	1.0015
30	.9915	.9925	.9935	.9945	.9955	.9965	.9970	.9980	.9990	1.0000	1.0010	1.0020
31	.9915	.9925	.9935	.9945	.9955	.9965	.9970	.9980	.9990	1.0000	1.0010	1.0020
32	.9910	.9920	.9930	.9940	.9950	.9960	.9970	.9980	.9990	1.0000	1.0010	1.0020
33	.9910	.9920	.9930	.9940	.9950	.9960	.9970	.9980	.9990	1.0000	1.0010	1.0020
34	.9910	.9915	.9925	.9940	.9950	.9960	.9970	.9980	.9990	1.0000	1.0010	1.0020
35	.9900	.9915	.9925	.9940	.9940	.9960	.9970	.9980	.9990	1.0000	1.0010	1.0020
36	.9900	.9910	.9920	.9930	.9940	.9955	.9965	.9980	.9990	1.0000	1.0010	1.0025
37	.9890	.9910	.9920	.9930	.9940	.9955	.9965	.9980	.9990	1.0000	1.0010	1.0025
38	.9890	.9910	.9920	.9930	.9940	.9955	.9965	.9980	.9990	1.0000	1.0010	1.0025
39	.9890	.9900	.9915	.9925	.9940	.9955	.9965	.9975	.9990	1.0000	1.0010	1.0025
40	.9890	.9900	.9915	.9925	.9940	.9950	.9960	.9975	.9990	1.0000	1.0010	1.0025

¹ The tabulated values are given to the nearest 0.0005.

TABLE II.—*Volume of milk and cream at various temperatures occupied by unit volume at 65° F. (20° C.)—Continued.*

Per cent- age of but- ter fat.	Temperature (° F.).											
	74	76	78	80	82	84	86	88	90	92	94	96
	Volume.											
0. 025	1. 0005	1. 0010	1. 0010	1. 0015	1. 0020	1. 0025	1. 0030	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050
1	1. 0005	1. 0010	1. 0010	1. 0015	1. 0020	1. 0025	1. 0030	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050
2	1. 0010	1. 0010	1. 0015	1. 0020	1. 0020	1. 0025	1. 0030	1. 0035	1. 0040	1. 0040	1. 0045	1. 0050
3	1. 0010	1. 0010	1. 0015	1. 0020	1. 0020	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0045	1. 0055
4	1. 0010	1. 0010	1. 0015	1. 0020	1. 0020	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050	1. 0055
5	1. 0010	1. 0015	1. 0020	1. 0020	1. 0025	1. 0030	1. 0035	1. 0035	1. 0045	1. 0045	1. 0050	1. 0060
6	1. 0010	1. 0015	1. 0020	1. 0020	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050	1. 0055	1. 0060
7	1. 0010	1. 0015	1. 0020	1. 0025	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050	1. 0055	1. 0060
8	1. 0010	1. 0015	1. 0020	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050	1. 0055	1. 0060	1. 0065
9	1. 0010	1. 0015	1. 0020	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050	1. 0055	1. 0060	1. 0065
10	1. 0015	1. 0020	1. 0025	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050	1. 0055	1. 0060	1. 0065
11	1. 0015	1. 0020	1. 0025	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0055	1. 0055	1. 0065	1. 0070
12	1. 0015	1. 0020	1. 0025	1. 0030	1. 0030	1. 0035	1. 0040	1. 0050	1. 0055	1. 0060	1. 0065	1. 0070
13	1. 0015	1. 0020	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050	1. 0055	1. 0060	1. 0065	1. 0070
14	1. 0015	1. 0020	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050	1. 0055	1. 0065	1. 0070.	1. 0075
15	1. 0015	1. 0025	1. 0030	1. 0030	1. 0035	1. 0040	1. 0045	1. 0055	1. 0060	1. 0065	1. 0070	1. 0075
16	1. 0015	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050	1. 0055	1. 0060	1. 0070	1. 0075	1. 0080
17	1. 0015	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0050	1. 0060	1. 0060	1. 0070	1. 0075	1. 0080
18	1. 0020	1. 0025	1. 0030	1. 0035	1. 0040	1. 0045	1. 0055	1. 0060	1. 0065	1. 0075	1. 0080	1. 0085
19	1. 0020	1. 0025	1. 0030	1. 0035	1. 0045	1. 0045	1. 0055	1. 0060	1. 0065	1. 0075	1. 0080	1. 0085
20	1. 0020	1. 0025	1. 0030	1. 0035	1. 0045	1. 0050	1. 0055	1. 0060	1. 0070	1. 0075	1. 0085	1. 0090
21	1. 0020	1. 0025	1. 0030	1. 0040	1. 0045	1. 0050	1. 0060	1. 0065	1. 0070	1. 0080	1. 0085	1. 0090
22	1. 0020	1. 0030	1. 0035	1. 0040	1. 0050	1. 0055	1. 0060	1. 0065	1. 0075	1. 0080	1. 0090	1. 0095
23	1. 0020	1. 0030	1. 0035	1. 0040	1. 0050	1. 0055	1. 0065	1. 0070	1. 0075	1. 0085	1. 0090	1. 0095
24	1. 0020	1. 0030	1. 0035	1. 0040	1. 0050	1. 0060	1. 0065	1. 0070	1. 0080	1. 0085	1. 0095	1. 0100
25	1. 0020	1. 0030	1. 0035	1. 0045	1. 0055	1. 0060	1. 0070	1. 0075	1. 0080	1. 0090	1. 0095	1. 0105
26	1. 0025	1. 0030	1. 0040	1. 0045	1. 0055	1. 0060	1. 0070	1. 0080	1. 0085	1. 0090	1. 0100	1. 0110
27	1. 0025	1. 0030	1. 0040	1. 0045	1. 0055	1. 0060	1. 0070	1. 0080	1. 0085	1. 0095	1. 0100	1. 0110
28	1. 0025	1. 0030	1. 0040	1. 0045	1. 0055	1. 0065	1. 0075	1. 0080	1. 0090	1. 0095	1. 0105	1. 0115
29	1. 0025	1. 0030	1. 0040	1. 0050	1. 0060	1. 0065	1. 0075	1. 0080	1. 0090	1. 0095	1. 0105	1. 0115
30	1. 0025	1. 0035	1. 0045	1. 0050	1. 0060	1. 0065	1. 0080	1. 0085	1. 0095	1. 0100	1. 0110	1. 0120
31	1. 0025	1. 0035	1. 0045	1. 0050	1. 0060	1. 0065	1. 0080	1. 0085	1. 0095	1. 0100	1. 0110	1. 0120
32	1. 0030	1. 0035	1. 0045	1. 0055	1. 0065	1. 0070	1. 0085	1. 0090	1. 0100	1. 0105	1. 0115	1. 0125
33	1. 0030	1. 0035	1. 0045	1. 0055	1. 0065	1. 0070	1. 0085	1. 0090	1. 0100	1. 0105	1. 0115	1. 0125
34	1. 0030	1. 0040	1. 0050	1. 0055	1. 0065	1. 0075	1. 0085	1. 0095	1. 0105	1. 0110	1. 0120	1. 0130
35	1. 0030	1. 0040	1. 0050	1. 0060	1. 0070	1. 0075	1. 0090	1. 0095	1. 0105	1. 0110	1. 0120	1. 0130
36	1. 0035	1. 0045	1. 0055	1. 0060	1. 0070	1. 0080	1. 0090	1. 0100	1. 0110	1. 0115	1. 0125	1. 0135
37	1. 0035	1. 0045	1. 0055	1. 0060	1. 0070	1. 0080	1. 0095	1. 0100	1. 0110	1. 0115	1. 0125	1. 0135
38	1. 0035	1. 0045	1. 0055	1. 0065	1. 0075	1. 0085	1. 0095	1. 0100	1. 0115	1. 0120	1. 0130	1. 0140
39	1. 0035	1. 0045	1. 0055	1. 0065	1. 0075	1. 0085	1. 0095	1. 0105	1. 0115	1. 0120	1. 0130	1. 0140
40	1. 0035	1. 0045	1. 0055	1. 0065	1. 0075	1. 0085	1. 0095	1. 0105	1. 0115	1. 0125	1. 0130	1. 0145

TABLE II.—*Volume of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.)—Continued.*

Percentage of butter fat.	Temperature (° F.).										
	98	100	102	104	106	108	110	112	114	116	118
	Volume.										
0.025	1.0055	1.0060	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105
1	1.0055	1.0060	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105
2	1.0055	1.0060	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0110
3	1.0060	1.0065	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0110
4	1.0060	1.0065	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0110
5	1.0060	1.0065	1.0070	1.0075	1.0080	1.0085	1.0085	1.0090	1.0095	1.0100	1.0110
6	1.0060	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0090	1.0095	1.0100	1.0110
7	1.0065	1.0070	1.0075	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105	1.0115
8	1.0065	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115
9	1.0065	1.0070	1.0080	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115
10	1.0070	1.0075	1.0080	1.0085	1.0090	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115
11	1.0070	1.0075	1.0080	1.0085	1.0090	1.0095	1.0095	1.0100	1.0105	1.0110	1.0115
12	1.0075	1.0080	1.0085	1.0090	1.0095	1.0095	1.0105	1.0110	1.0115	1.0120	1.0125
13	1.0075	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115	1.0120	1.0125
14	1.0080	1.0085	1.0090	1.0095	1.0100	1.0100	1.0110	1.0115	1.0120	1.0125	1.0130
15	1.0080	1.0085	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115	1.0120	1.0125	1.0130
16	1.0085	1.0090	1.0095	1.0100	1.0105	1.0110	1.0115	1.0120	1.0125	1.0130	1.0135
17	1.0085	1.0090	1.0095	1.0105	1.0105	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140
18	1.0090	1.0095	1.0100	1.0105	1.0110	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145
19	1.0090	1.0095	1.0100	1.0110	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145
20	1.0095	1.0100	1.0105	1.0110	1.0115	1.0125	1.0130	1.0135	1.0140	1.0145	1.0150
21	1.0095	1.0100	1.0105	1.0115	1.0120	1.0125	1.0130	1.0135	1.0145	1.0150	1.0155
22	1.0100	1.0105	1.0110	1.0120	1.0125	1.0130	1.0135	1.0140	1.0150	1.0155	1.0160
23	1.0105	1.0105	1.0115	1.0120	1.0125	1.0130	1.0140	1.0145	1.0150	1.0155	1.0160
24	1.0105	1.0110	1.0120	1.0125	1.0130	1.0135	1.0145	1.0150	1.0155	1.0160	1.0165
25	1.0110	1.0115	1.0120	1.0130	1.0135	1.0140	1.0145	1.0150	1.0160	1.0165	1.0170
26	1.0115	1.0120	1.0125	1.0135	1.0140	1.0145	1.0155	1.0160	1.0165	1.0170	1.0180
27	1.0115	1.0120	1.0130	1.0135	1.0140	1.0150	1.0155	1.0160	1.0170	1.0170	1.0180
28	1.0120	1.0125	1.0130	1.0140	1.0145	1.0150	1.0160	1.0165	1.0175	1.0175	1.0185
29	1.0120	1.0130	1.0135	1.0140	1.0150	1.0155	1.0160	1.0165	1.0175	1.0180	1.0185
30	1.0125	1.0130	1.0135	1.0145	1.0155	1.0155	1.0165	1.0170	1.0175	1.0180	1.0190
31	1.0125	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175	1.0180	1.0185	1.0190
32	1.0130	1.0135	1.0140	1.0150	1.0160	1.0165	1.0170	1.0180	1.0185	1.0190	1.0195
33	1.0130	1.0140	1.0145	1.0155	1.0160	1.0165	1.0170	1.0180	1.0185	1.0190	1.0195
34	1.0135	1.0140	1.0150	1.0160	1.0165	1.0170	1.0175	1.0185	1.0190	1.0195	1.0200
35	1.0135	1.0145	1.0150	1.0160	1.0165	1.0170	1.0180	1.0190	1.0195	1.0200	1.0205
36	1.0140	1.0145	1.0155	1.0165	1.0170	1.0175	1.0185	1.0195	1.0200	1.0205	1.0210
37	1.0145	1.0150	1.0160	1.0165	1.0175	1.0180	1.0185	1.0195	1.0200	1.0205	1.0210
38	1.0150	1.0155	1.0165	1.0170	1.0175	1.0185	1.0190	1.0200	1.0210	1.0215	1.0215
39	1.0150	1.0160	1.0165	1.0170	1.0180	1.0185	1.0195	1.0205	1.0210	1.0215	1.0220
40	1.0155	1.0165	1.0170	1.0175	1.0185	1.0190	1.0200	1.0210	1.0215	1.0220	1.0230

TABLE II.—*Volume of milk and cream at various temperatures occupied by unit volume at 68° F. (20° C.)—Continued.*

Percentage of butterfat.	(Temperature (° F.).										
	120	122	124	126	128	130	132	134	136	138	140
	Volume.										
0.025	1.0110	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
1	1.0110	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
2	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
3	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
4	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
5	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
6	1.0115	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0170	1.0175
7	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0160	1.0165	1.0170	1.0175
8	1.0120	1.0125	1.0130	1.0135	1.0140	1.0145	1.0155	1.0155	1.0165	1.0170	1.0175
9	1.0120	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0180
10	1.0120	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0180
11	1.0120	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0180
12	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180
13	1.0130	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180
14	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185
15	1.0135	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185
16	1.0140	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185	1.0190
17	1.0145	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0175	1.0180	1.0185	1.0190
18	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185	1.0185	1.0190	1.0195
19	1.0150	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185	1.0185	1.0190	1.0195
20	1.0155	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185	1.0190	1.0195	1.0200	1.0205
21	1.0160	1.0165	1.0170	1.0175	1.0180	1.0185	1.0190	1.0190	1.0195	1.0200	1.0205
22	1.0165	1.0170	1.0175	1.0180	1.0185	1.0190	1.0190	1.0195	1.0200	1.0205	1.0210
23	1.0165	1.0170	1.0175	1.0180	1.0185	1.0190	1.0195	1.0195	1.0200	1.0205	1.0210
24	1.0170	1.0180	1.0185	1.0190	1.0195	1.0200	1.0205	1.0205	1.0210	1.0215	1.0220
25	1.0175	1.0180	1.0185	1.0190	1.0195	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225
26	1.0185	1.0190	1.0195	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235
27	1.0185	1.0190	1.0195	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235
28	1.0190	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235	1.0240	1.0245
29	1.0195	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235	1.0240	1.0245
30	1.0195	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0235	1.0240	1.0245	1.0250
31	1.0200	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235	1.0240	1.0245	1.0250
32	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235	1.0240	1.0245	1.0250	1.0255
33	1.0205	1.0210	1.0215	1.0220	1.0225	1.0230	1.0235	1.0240	1.0245	1.0250	1.0255
34	1.0210	1.0215	1.0220	1.0225	1.0230	1.0240	1.0245	1.0245	1.0250	1.0255	1.0260
35	1.0210	1.0215	1.0220	1.0225	1.0230	1.0240	1.0245	1.0250	1.0250	1.0255	1.0260
36	1.0215	1.0225	1.0230	1.0235	1.0240	1.0245	1.0250	1.0255	1.0260	1.0265	1.0270
37	1.0215	1.0225	1.0230	1.0235	1.0240	1.0245	1.0250	1.0255	1.0260	1.0265	1.0270
38	1.0220	1.0230	1.0235	1.0240	1.0245	1.0250	1.0255	1.0260	1.0265	1.0270	1.0280
39	1.0225	1.0235	1.0240	1.0245	1.0250	1.0255	1.0260	1.0265	1.0270	1.0275	1.0280
40	1.0235	1.0240	1.0245	1.0255	1.0260	1.0265	1.0270	1.0275	1.0280	1.0285	1.0290

SPECIFIC GRAVITY OF MILK AND CREAM.

Table III covers the specific gravity of milk and cream determined at 68° F. (20° C.) in terms of water at the same temperature as unity.

TABLE III.—*Specific gravity of milk and cream corresponding to various percentages of butter fat at 68° F.*

Per-centage of fat.	Specific gravity.	Per-centage of fat.	Specific gravity.	Per-centage of fat.	Specific gravity.	Per-centage of fat.	Specific gravity.
0.025	1.037	11	1.024	21	1.012	31	1.003
1	1.036	12	1.022	22	1.011	32	1.002
2	1.035	13	1.020	23	1.010	33	1.001
3	1.034	14	1.019	24	1.009	34	1.000
4	1.032	15	1.018	25	1.008	35	.999
5	1.031	16	1.017	26	1.008	36	.999
6	1.030	17	1.016	27	1.007	37	.998
7	1.029	18	1.015	28	1.006	38	.997
8	1.027	19	1.014	29	1.005	39	.996
9	1.026	20	1.013	30	1.004	40	.995
10	1.025						

FREEZING POINT OF MILK.

The freezing point of milk depends upon its composition, but is always lower than that of water. The freezing point of market milk generally varies from 31° to 29° F. The addition of water to milk serves to raise the freezing point toward that of pure water, 32° F., while, on the other hand, the addition of fats, solids, etc., tends to lower the freezing point, as does also the increase in acidity. Upon these variations in the freezing point is based the cryscopical method of determining the addition of water to milk.

EFFECT OF FREEZING ON MILK.

While the action of cold on milk at a temperature above the freezing point has no other effect than that of varying the density and viscosity, at a temperature below the freezing point it changes the chemical and physical composition.

According to Kasdorf,¹ when raw milk which was partly frozen at a temperature of 10.5° F., in the ordinary container, during transportation, it was found that ice first formed around the sides and at the bottom of the can; the central core contained most of the casein, sugar, and other mineral ingredients, while most of the fat was found in the top layer of the liquid portion.

When milk has been frozen gradually, without agitation, and thawed out clots will be found floating in the liquid, composed mostly of albumen and fat, which may be dissolved by cooking; on the other hand, if the milk is preserved in a frozen condition for three or four weeks these clots will be very hard to dissolve, and the difficulty experienced in dissolving them increases as the length of time the

¹ Kasdorf, Otto. *Eis und Kälte in Molkereibetrieb*. Leipzig, 1904, p. 20.

milk is preserved in a frozen state. For this reason the freezing of milk, for the purpose of transportation, has hitherto been little used.

If the milk is held at 32° F. for a few days, some types of bacteria may grow and multiply slowly. With a good quality of milk, i. e., that containing few bacteria, it may take weeks or even months for them to gain great headway. What few bacteria develop at low temperatures are of different species from those ordinarily found at the higher temperatures, and they may produce marked changes in the chemical composition of the milk without especially changing its appearance. Consequently, it is unsafe to assume that milk which has been held for several days at a low temperature is in good condition. According to Pennington¹ milk exposed continually to a temperature of 29° to 32° F. causes, after a lapse of from 7 to 21 days, the formation of small ice crystals which gradually increase until the milk is filled with them, and there may be an adherent layer on the walls of the vessel. The milk does not freeze solid. In spite of the fact that the milk was a semisolid mass of ice crystals, an enormous increase in bacterial content took place. Though the bacterial content was numerically in the hundreds of millions per cubic centimeter, there was neither taste nor odor to indicate that such was the case. Neither did the milk curdle when heated, and the unfitness of the milk for household purposes would not ordinarily be detected until the lactic acid bacteria decreased in numbers and the putrefactive bacteria began to develop.

THE INFLUENCE OF TEMPERATURE ON THE BACTERIOLOGICAL FLORA OF MILK.

Each species of bacterium found in milk and each particular variety has an upper and lower temperature limit beyond which it does not grow, and a certain temperature, called the optimum, at which it grows best.

The optimum temperature of most forms occurring in milk is between 70° and 100° F. As the temperature of milk is lowered the rate of growth is diminished until at 40° F. the multiplication is very slow and at a temperature just above the freezing point the development practically ceases; in fact, there is an apparent decrease in the number, at least for a short time. The action of cold at this temperature, however, does not totally destroy life in the bacteria, but causes them to lie dormant. When the temperature of the milk is raised they again begin to multiply. As an illustration of the relative variation in the growth of bacteria in milk held at different temperatures, one writer gives the data found in Table IV, in which 1 is assumed to represent the number of bacteria in the fresh milk, and the relative numbers which will be found at the end of 6, 12, 24, and 48 hours, at the two temperatures, are shown in the succeeding col-

¹ Pennington, Mary E. Bacterial growth and chemical changes in milk kept at low temperatures. *Journal of Biological Chemistry*, vol. 4, nos. 4 and 5, pp. 353-393. Baltimore, 1908.

umns. These figures are based on a number of actual counts and illustrate the effect of a difference of 18° on the multiplication of bacteria. If the milk had contained at the beginning 1,000 bacteria, the part held at the lower temperature would have contained at the end of 24 hours only 4,100 bacteria, while the other would have contained at the same stage 6,128,000. Table V, from Bulletin 133 (Extension Bulletin 8) of the agricultural experiment station of Nebraska, illustrates the importance of holding cream at low temperatures.

TABLE IV.—*Multiplication of bacteria in milk held at different temperatures.*¹

Milk held at—	Relative number of bacteria held at—				
	0 hours.	6 hours.	12 hours.	24 hours.	48 hours.
50° F.....	1	1.2	1.5	4.1	6.2
68° F.....	1	1.7	24.2	6, 128	357, 499

¹ Rogers, Lore A. Bacteria in milk. U. S. Department of Agriculture, Farmers' Bulletin 490. Washington, D. C.

TABLE V.—*The effect of temperature on the growth of bacteria in cream.*

Temperature of cream.	Time held.	Number of bacteria per c. c.	Temperature of cream.	Time held.	Number of bacteria per c. c.
° F.	Hours.		° F.	Hours.	
32.....	10	3, 300	70.....	11	188, 000
50.....	10	11, 580	80.....	11	2, 631, 000
60.....	10½	15, 120	90.....	11½	4, 426, 000

THE INFLUENCE OF TIME ON THE BACTERIOLOGICAL FLORA OF MILK.

The influence of temperature and time bear certain definite relations to each other; hence, a study of one necessarily includes a study of the other. Table VI serves to illustrate the effect of time as well as temperature on the keeping qualities of milk. If the table is read downward we note the effect of temperature and if read across the effect of time. When milk is first drawn from the cow it usually contains bacteria, even though it is produced under sanitary conditions, and if held at the ordinary temperature of the surrounding air in a short while the bacteria will grow and increase in numbers so rapidly that when such milk reaches the consumer it will contain many thousand bacteria per cubic centimeter.

Conn furnishes an example of milk giving the following results:

	Bacteria per c. c.
Milk drawn at 59° F.....	153, 000
After 1 hour.....	616, 000
2 hours.....	539, 000
4 hours.....	680, 000
7 hours.....	1, 020, 000
9 hours.....	2, 040, 000
24 hours.....	85, 000, 000

According to Park,¹ two samples of milk maintained at different temperatures for 24, 48, 96, and 168 hours, respectively, showed the development of bacteria as indicated in Table VI. The first sample was obtained under the best possible conditions, while the second sample was obtained in the usual way. (The figures of the second sample are heavy face in the table.) When received the first sample contained 3,000 bacteria and the second 30,000 per cubic centimeter.

TABLE VI.—*Effect of time and temperature on the growth of bacteria in milk.*

Temperature.	24 hours.	48 hours.	96 hours.	168 hours.
32° F. (0° C.).....	2, 400	2, 100	1, 850	1, 400
	30, 000	27, 000	24, 000	19, 000
39° F. (4° C.).....	2, 500	3, 600	218, 000	4, 200, 000
	38, 000	56, 000	4, 300, 000	38, 000, 000
42° F. (5° C.).....	2, 600	3, 600	400, 000	
	43, 000	210, 000	5, 760, 000	
46° F. (6° C.).....	3, 100	12, 000	1, 480, 000	
	42, 000	360, 000	12, 200, 000	
50° F. (10° C.).....	11, 600	540, 000		
	89, 000	1, 940, 000		
55° F. (13° C.).....	18, 800	3, 400, 000		
	187, 000	38, 000, 000		
60° F. (16° C.).....	180, 000	28, 000, 000		
	900, 000	168, 000, 000		
68° F. (20° C.).....	450, 000	25, 000, 000, 000		
	4, 000, 000	25, 000, 000, 000		
86° F. (30° C.).....	1, 400, 000, 000			
	14, 000, 000, 000			
94° F. (35° C.).....	25, 000, 000, 000			
	25, 000, 000, 000			

In Table VI it will be noted that at 32° F. there is an actual decrease in the number of bacteria in both samples of milk during the 168 hours, while at all other temperatures there is an increase in the number of bacteria. Ordinarily the consumer receives milk when it is from 24 to 48 hours old; hence it becomes an easy matter to deliver the milk in good condition, providing the milk is produced under sanitary conditions and is properly cooled and held at a temperature of 50° F. or below. An examination of the tables and figure will show how intimately the two influences of time and temperature act and interact in relation to the multiplication of bacteria in milk. Figure 2 is a graphical representation of the relation of temperature to bacterial growth in milk, taken from Bulletin 26 of the Storrs (Conn.) Agricultural Experiment Station.²

At *a* is represented a single bacterium; at *b* is shown the progeny resulting from the growth of a single bacterium in 24 hours in milk kept at a temperature of 50° F.; at *c* is represented the progeny from a single bacterium in 24 hours in milk kept at 70° F. At 50° the multiplication was fivefold, at 70° the multiplication was seven

¹ Park, William Hallock. The great bacterial contamination of the milk of cities. Can it be lessened by the action of health authorities? *Journal of Hygiene*, vol. 1, no. 3, pp. 391-406. Cambridge, July, 1901.

² Conn, Herbert William. The relation of temperature to the keeping property of milk. *Connecticut (Storrs) Agricultural Experiment Station Bul. 26*. Storrs, 1903.

hundred and fifty fold. The figure shows graphically what a decided influence the dairyman can exert upon the keeping of his milk by a lowering of temperature only 20° .

From the foregoing it is obvious that proper refrigeration is of the utmost importance in the preservation of milk. In fact, without thorough cooling it is impracticable to keep milk for any considerable length of time in a condition that would justify its use for household purposes. It should be cooled to 50° F. or below as quickly as possible after it is drawn from the cow, as such cooling will at once check the increase in bacteria.



FIG. 2.—Graphical representation of the relation of temperature to bacterial growth in milk.

COOLING BY MEANS OF SALT AND ICE MIXTURES.

Where a small amount of refrigeration is required it is often produced by a mixture of common salt and ice. The action of the mixture in lowering the temperature below 32° F. is as follows: When two solid bodies, as salt and ice, mix to form a liquid a certain amount of heat becomes latent, called the latent heat of solution. Since this latent heat is taken from the mixture itself the temperature falls correspondingly. The temperature obtained by a salt and ice mixture depends principally on the relative proportions of the mixture, and to a less extent on the rate at which the heat is supplied from the outside, the size of the ice lumps and salt particles, and the amount and density of the resulting brine. Hence it is impracticable to give

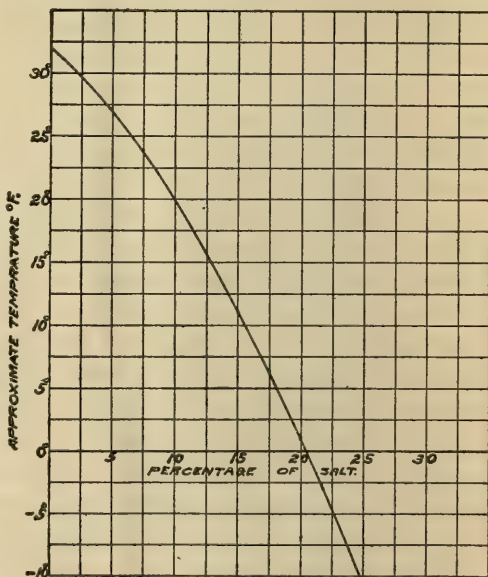


FIG. 3.—Approximate temperatures obtained with different proportions of salt.

other than approximate temperatures with fixed ratios of salt and ice. From the curve in figure 3 the approximate temperature resulting from different proportions, by weight, of salt and ice may be obtained. If, for example, we desire to know what temperature may be obtained by using a mixture of salt and ice containing 15 per cent of salt, follow the vertical line marked "15 per cent of

salt" upward until it cuts the curve, then read opposite on the vertical line marked "Approximate temperature ° F., 11°." The curve in figure 3 was plotted from the figures in Table VII, which gives the approximate temperatures obtained with different proportions of salt and ice.

TABLE VII.—*Approximate temperatures obtained with different proportions of salt and ice.*

Per cent of salt in mixture.	Temperature of mixture.	Per cent of salt in mixture.	Temperature of mixture.
	° F.		° F.
0	32	15	11
5	27	20	1.5
10	20	25	-10

One pound of ice, in melting, absorbs 144 B. T. U. This is known as the latent heat of fusion of ice. Salt in dissolving also absorbs heat, called the latent heat of solution, which varies in amount, depending on the density and temperature of the resulting brine.

The heat of solution of salt in water at 32° F. varies from 58 to 16 B. T. U., depending on the final strength of the brine obtained. Table VIII gives the heat of solution of 1 pound of salt dissolved in water at 32° F. up to the concentration given by the numbers of pounds of salt dissolved in 100 pounds of water.

TABLE VIII.—*Refrigeration available with different proportions of ice and salt.*

Salt per 100 pounds water.	Heat of solution.	Total heat of resulting solution.	Heat required per pound of mixture.	Salt per 100 pounds water.	Heat of solution.	Total heat of resulting solution.	Heat required per pound of mixture.
Pounds.	B. T. U.	B. T. U.	B. T. U.	Pounds.	B. T. U.	B. T. U.	B. T. U.
1	58.0	14,458	143.0	20	27.0	14,940	124.5
5	49.7	14,668	139.5	25	22.5	14,962	119.5
10	40.5	14,806	134.5	30	19.1	14,973	115.0
15	33.0	14,895	129.5	35	16.4	14,974	111.0

The curve in figure 4, based on the percentage of salt, shows the amount of refrigeration available per pounds of ice and salt mixture. This curve was plotted from the figures given in Table VIII corrected to a percentage basis, which were calculated from the melting of ice at 32° F. into a liquid at the same temperature. If, however, the salt is added to the ice at a temperature varying from 32° F. or, if the resulting brine is allowed to escape at a temperature other than 32° F., the amount of available refrigeration must be corrected accordingly. These corrections are determined by multiplying weights, in pounds of salt and brine, by their respective specific heats and by their difference in temperature from 32° F. The specific heat of dry salt may be taken as 0.214, and as the specific heat of salt brine varies with its density, it may be obtained from Table IX or from curve figure 5, which is plotted from the figures contained in the table.

TABLE IX.—*Specific heat of brine with different percentages of salt.*

Per cent of salt.	Specific heat of brine.	Per cent of salt.	Specific heat of brine.
0	1.000	15	0.855
1	.992	20	.829
5	.960	25	.783
10	.892		

Usually salt when added to ice is of a higher temperature than that of the ice; consequently the correction for its heat above 32° F.

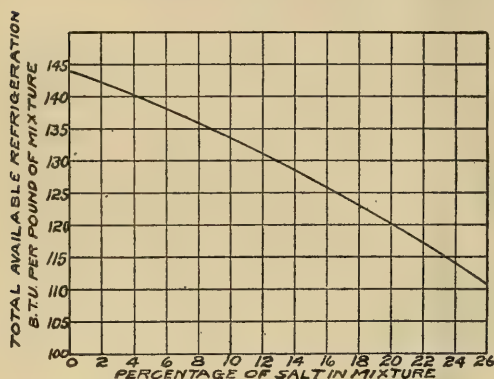


FIG. 4.—Refrigeration available with different percentages of salt.

must be subtracted from the available refrigeration shown by the curve, figure 4; and if the brine is allowed to escape at a temperature below 32° F. the refrigeration lost in the discharge brine must be subtracted, while, on the other hand, if the discharge brine is at a temperature higher than 32° F. the correction must be added.

If given amounts of ice and salt, at a temperature of 32° F. are mixed together and the mixture supplied with sufficient heat to melt the ice and dissolve the salt and raise the temperature of the resulting brine to the original temperature of 32° F., then the total amount of heat absorbed by the reaction will be the sum of the latent heat of the ice and the heat of solution of the salt to form the resulting brine of the density which will result from the particular proportion of salt and ice chosen. As an example, under the foregoing conditions, if 100 pounds of dry salt is added to 900 pounds of ice the total available refrigeration is $1,000 \times 133 = 133,000$ B. T. U. The available refrigeration per pound of mixture, 133 B. T. U., is taken from curve in figure 4. If the salt added is at a higher temperature than 32° F., say 60°

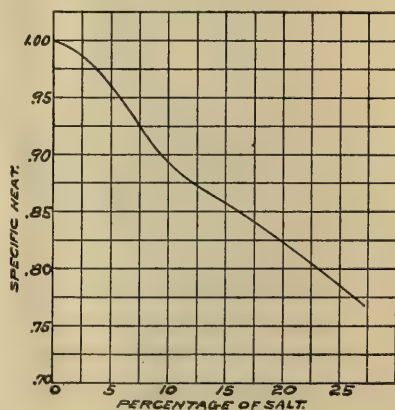


FIG. 5.—Specific heat of common salt brine, with different percentages of salt.

F., then the available refrigeration will be $133,000 - [100 \times 0.214 (60-32)] = 132,401$ B. T. U., or 132.4 B. T. U. per pound of mixture. If the resulting brine is allowed to escape at 25° F., the available refrigeration is $133,000 - [1,000 \times 0.892 (32-25)] = 126,756$ B. T. U., or 126.7 B. T. U. per pound of mixture. Or, in other words, there is lost in the first case $100 \times 0.214 (60-32) = 599$ B. T. U., and in the second case, $1,000 \times 0.892 (32-25) = 6,244$ B. T. U., or a total loss, if the salt is added at 60° F. and the brine allowed to escape at 25° F., of $599 + 6,244 = 6,843$ B. T. U. Under these conditions the available refrigeration is $133,000 - 6,843 = 126,157$ B. T. U., or 126 B. T. U. per pound of mixture.

REFRIGERATION AS APPLIED TO MILK PLANTS, CREAMERIES, AND DAIRIES.

The function of refrigerating apparatus, whether it is a refrigerating machine or a bunker filled with ice, is to provide a heat-absorbing medium which, after absorbing heat in the cold-storage room, may be removed. After it has been removed from the coolers it may be divested of its heat and allowed to return to the cooler for the purpose of absorbing more heat, as is the case when some volatile liquid is used, or it may be allowed to go to waste and a new supply introduced, as in the case of cooling with ice.

ICE BUNKERS.

OVERHEAD BUNKERS.

One of the simplest methods of cooling a cold-storage room is that of an ice bunker, the principle of which is shown in figure 6 and consists of a water-tight floor located over the compartments to be cooled. The ice is piled on the floor through an opening at or near the top of the room and the cooling is effected by the natural circulation of air up and over the ice and down into the compartment in which the goods to be cooled are stored. The movement of air is naturally slow, as the power available is the difference between the weights of the ascending column of warm air and the descending column of cold air. As the air in contact with the ice is cooled it flows down into the room below, where it comes in contact with the warm goods in storage and absorbs heat from them, and as it becomes warmer is forced up to the bunker, where it is gradually cooled, thus producing a circulation. The movement of air may be increased and lower temperatures obtained by employing a fan driven by an outside source of power, or a mixture of salt and ice may be used in the bunker, in which case a lower temperature may be obtained, but in either case at the expense of a greater consumption of ice,

for, as previously stated, the use of a mixture of salt and ice in a refrigerator does not increase the cooling capacity of a given amount of ice, but the effect is to cause the ice to melt more rapidly and thus absorb heat more quickly. In other words, the melting point of ice is lowered when mixed with salt. One pound of ice in melting absorbs 144 heat units, either with or without salt. With salt the absorption is quickened, hence a lower temperature for a shorter

time. Therefore there is no gain in efficiency by employing a mixture of salt and ice; in fact, there is a loss in efficiency due to the heat of solution.

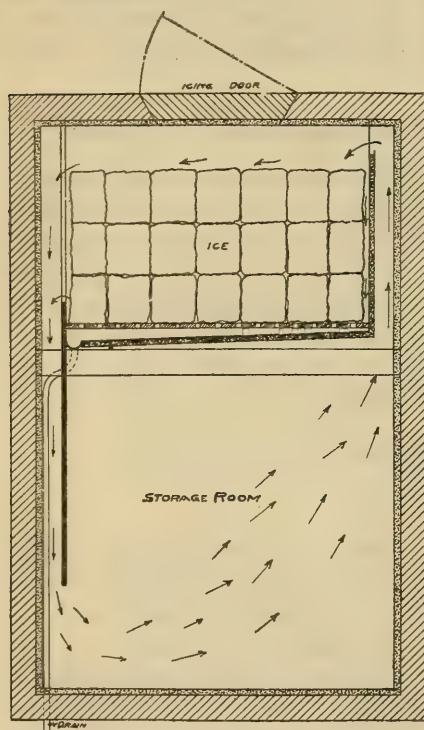


FIG. 6.—Overhead ice bunker.

difference in temperature between the air in the bunker and that in the compartment below would be required.

Ample spaces for air ducts should be provided between the sides of the bunker and the walls of the cold-storage compartment in order to permit the air to circulate freely. The cross-sectional area of the ducts should be from 10 to 15 per cent of the area of the ceiling. The floor of the bunker and the walls of the air ducts should be well insulated to prevent the too rapid cooling of the relatively warmer ascending air as well as that lying next the floor of the bunker. Rapid cooling of the air at these points tends to check the circulation by reducing the difference in temperature between the warm

Ice bunkers for cooling purposes, when located over the compartment to be cooled, should be made in the form of a box with one side removed, as shown in figure 6, in order to assist the air currents. With this form of construction the air, as it is gradually cooled, flows to the left down over the ice, while the warm air rises on the right to take its place. It is obvious that if the bunkers should be made in the form of a rectangular box the air would have a tendency to flow off in all directions and give rise to conflicting currents which would retard the circulation and for the same rate of circulation a greater

air in the ducts and that in the bunker. With properly insulated bunkers and liberal-sized ducts the circulation should be sufficiently rapid to carry any air saturated with moisture to the ice bunker before its moisture can be precipitated by coming in contact with the cold walls of the storage room. With properly proportioned ducts and insulated walls the excess moisture will be precipitated in the ice bunkers and run off with the melted ice. If the air ducts and bunker walls and floor are not sufficiently insulated the excess of moisture will be condensed on them and will drip down on the goods in storage.

Provision should be made for thorough drainage and the drain-pipe should be effectively trapped or sealed to prevent the outside air from entering the cold-storage room. An efficient water seal may be had by allowing the outer end of the drainpipe to extend below the surface of the water in a cooling tank outside the room, and as the water from the melted ice is approximately 32° F. it may be utilized for further refrigerating purposes.

As the melting point of ice is 32° F., it is obvious that, in a room cooled by ice, the temperature must necessarily be somewhat higher. In practice the temperatures obtained are rarely below 40° to 45° F. during warm weather. In addition to the disadvantage of the comparatively high temperatures obtained by using ice as the cooling medium in cold storage, the excessive moisture present in the air, together with the slop incident to its use, makes it undesirable. The nearer the temperature of the air in a room cooled by ice approaches that of the melting ice the more sluggish becomes the circulation and the higher the percentage of moisture contained in the air. Moisture in a cold-storage room favors the growth of molds and bacteria, which rot the floors and walls of the room, as well as the goods stored; consequently sensitive goods like dairy products are liable to be damaged by such conditions, especially if kept in storage for a considerable length of time. However, in small plants or on the farm, where goods are stored for a short period only and where ice may be had at a nominal cost, either natural or artificial, this method of cooling is employed to advantage.

Great care should be exercised to prevent any cross currents of air in the cooling room, for when such currents are present there is danger of the cold air and warm air coming in contact with each other, in which case condensation will be sure to take place on the cool surfaces of the walls and ducts, thereby preventing the displacement of the impure gases to be condensed on the surface of the ice in the bunker and removed with the drip.

It is very important that a positively guided circulation of air be maintained. In order for the cold air to be most effective it should

be admitted into the storage room at a low level, as indicated in figures 6 and 7. The cold air will then pass over the goods in storage, and as it becomes warmer will gradually rise to the bunker, where it is recooled. As natural circulation is brought about by the difference in temperature between the warm air and cold air, which is only a degree or two, advantage must be taken of the difference in height of the respective columns. The simplest and most effective way to accomplish this is to extend the cold-air duct to within about 2 feet of the floor. The inner side of this duct should be insulated to prevent condensation. The uptake duct should be similarly insulated

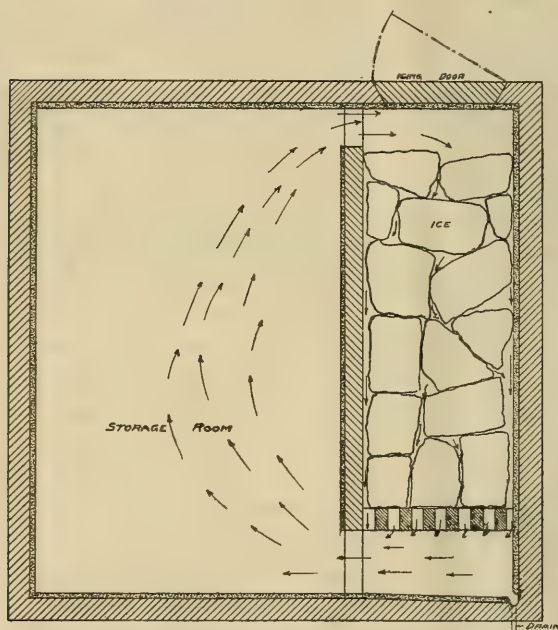


FIG. 7.—Side ice bunker.

and should extend from the bunker floor to near the ceiling of the room, leaving an area equal to the cross-sectional area of the warm-air duct. The warm-air duct should be located on the warmest wall of the room in order to take advantage of the natural air circulation, and for the same reason the cold-air duct should be on the coldest wall.

SIDE BUNKERS.

Ice bunkers are often constructed as shown in figure 7, and the same care in construction and insulation should be observed as in the overhead type of bunker.

GRAVITY BRINE SYSTEM.

The system illustrated in figure 8 has made it possible to obtain temperatures considerably lower than can be obtained with the bunker system. It consists of a tank filled with ice and salt, in the proportions required to produce the desired temperatures, and an endless-pipe circuit.

The pipe is completely filled with a brine solution of the proper density to insure against freezing. It is customary to use a solution of calcium chlorid, as lower temperatures are obtained without danger of freezing and the corrosive action is less than that of com-

mon salt. The solution should not be stronger than the temperature to be maintained requires, as the specific heat of brine decreases as the strength of the solution increases. A part of the pipe coils are placed in the tank containing the mixture of salt and ice, and a part are led down into the cooling room below. The coils of pipe that are in the cooling room absorb heat from the stored goods

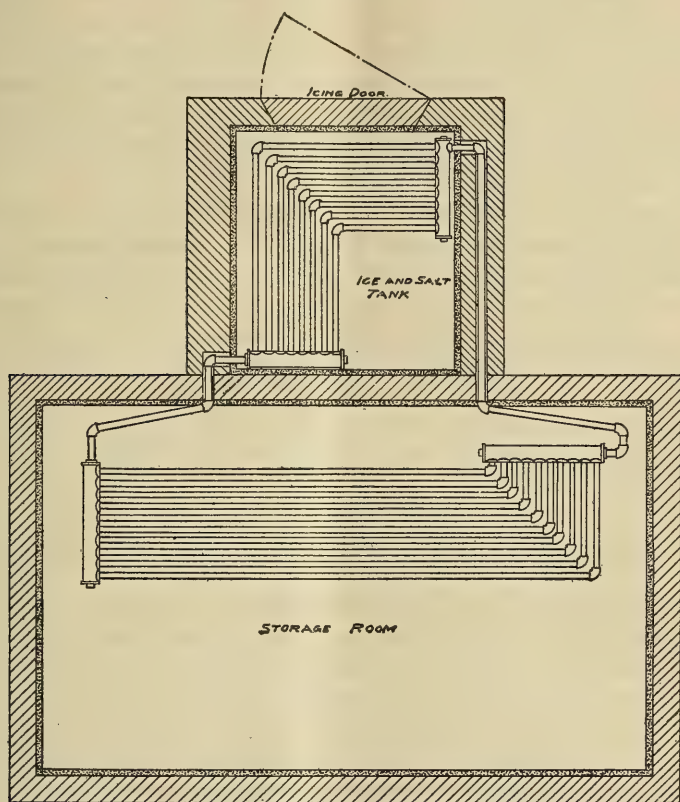


FIG. 8.—Gravity brine system.

and those in the tank give up heat to the freezing mixture of salt and ice.

The operation of this system is as follows: The brine in that part of the pipe circuit in the tank becomes heavier as it is cooled and flows down into the storage room, forcing the warmer and therefore lighter brine up into the coils in the tank. The heat absorbed in the storage room is transferred to the mixture in the tank by the natural circulation of the medium. This system is to a certain extent automatic in its operation, as an abnormal rise in temperature of the storage compartment from any cause increases the velocity of the brine circulation and therefore increases the re-

frigerating capacity of the system. With this system it is possible to prevent the air in the cold-storage compartment from becoming contaminated by contact with the melted ice and insanitary bunkers, as is the case when ice is used. In addition, a drier, purer air is maintained in the storage room.

In milk plants, creameries, and dairies, where the cooling is done in a comparatively short time, it is necessary to have a large storage tank for brine, which may be cooled in the afternoon or overnight and held for quick action when needed. As the temperature of the brine in the storage tank will gradually rise as the work of cooling the milk goes on, the volume required will depend on the amount of milk to be handled and the range of temperature through which it is to be cooled.

For example, if there are 1,000 pounds of milk to be cooled from an initial temperature of 90° F. to a final temperature of 35° F., the heat that must be removed is $1,000 \times 0.95 (90-35) = 52,250$ B. T. U. Then, if the initial temperature of the brine is 25° F., the allowable rise in temperature will be 10°, and if the specific heat of the brine is 0.83, neglecting radiation, the amount necessary will be $\frac{52,250}{0.83 \times 10} = 6,292$ pounds, or 87.5 cubic feet. It is assumed above that the brine is pumped from a brine tank through some form of tubular cooler.

CONSTRUCTION AND LOCATION OF COLD-STORAGE ROOMS.

In the construction of cold-storage rooms consideration should be given to the relations that the lateral dimensions bear to the cubical space of the room. This is an important factor in the construction of refrigerators and is one to which but little attention is given. It is important that the shape of the room should be given first consideration, and unless there are some local conditions that compel a different arrangement it should be built, as nearly as possible, in the form of a cube. This will present the smallest exterior surface for a given cubical space for any practical form of construction. For very small rooms, however, of less than 1,000 cubic feet capacity, it is impracticable to build them in the form of a cube, as the height should be 10 or 12 feet. This height affords a better circulation of air, and consequently a more uniform temperature, a purer, drier air, and more satisfactory refrigeration.

Where mechanical refrigeration is employed this height is necessary in order to provide space for the coil bunkers unless wall coils are used, in which case the height may be less. The circulation of air, however, is not so good with wall coils as with a bunker loft. If very cold temperatures are not required, as in the case of ordinary ice

boxes, a lower room may answer the purpose. As an illustration of the saving of material in construction and in refrigeration, let us consider two cold-storage rooms, each of 1,000 cubic feet capacity; one room to be in the form of a perfect cube, 10 by 10 by 10 feet = 1,000 cubic feet; the other room to be 10 by 6 feet by 16 feet 8 inches = 1,000 cubic feet. The total square feet of surface in the first room is 600; the total square feet of surface in the second room is 653; therefore, for the same cubical contents, the second room has 8.8 per cent more radiating surface and will require 8.8 per cent more material in construction.

The cold-storage room should be where it is protected as much as possible from the direct rays of the sun. Unless some natural protection is afforded, such as trees or buildings, the cold-storage room should be in the northeast corner of the building.

In the construction of a new plant advantage should be taken of the actual condition surrounding the proposed building site. Very often considerable may be gained by proper location of the building and arrangement of machinery.

For insulation of cold-storage rooms the reader is referred to the matter under the heading "Insulation."

PRINCIPLES OF MECHANICAL REFRIGERATION.

When a solid or a liquid changes its state or condition, as when a solid is converted into a liquid or a liquid into a gas or vapor, the change of state or condition is in each case accompanied by the absorption of heat. This absorption of heat, as previously explained, is called "latent heat;" that is, heat that can not be measured by a thermometer; and in order to transfer a substance from one state to another it is only necessary to supply or extract heat. For instance, if we take 1 pound of ice at zero temperature, Fahrenheit scale, and apply heat, the temperature will rise until it reaches 32°. If we continue the application of heat the ice will begin to melt, and after we have supplied sufficient heat the 1 pound of ice will have changed to water at 32° F., the same temperature at which the ice commenced to melt. If the application of heat is continued the water will grow warmer, but at a slower rate. It now takes about double the amount of heat to raise the 1 pound 1 degree as water that it did to raise the 1 pound 1 degree as ice. In other words, the specific heat of water is approximately double that of ice.

When sufficient heat has been added to raise the 1 pound of water to a temperature of 212° F., another critical point is reached at which further application of heat to the water, under atmospheric pressure, will not increase its temperature, but changes it into steam at a temperature of 212°. Figure 9 shows graphically the relation of heat to temperature.

It will be noted from figure 9 that to raise the temperature of the 1 pound of ice from zero to the melting point (32° F.) 16 B. T. U. were expended; in melting the ice, 144 B. T. U.; in raising the water to the boiling point, 180 B. T. U.; and to evaporate the water, 970.4 B. T. U. If the operation is reversed, the heat being extracted instead of being added, the curve will follow backward on itself to the starting point.

The latent heat of fusion and the latent heat of vaporization are represented on the diagram by the two lines parallel to the horizontal base line, the length of the lines representing to scale the amount of heat expended in molecular work in separating the molecules of the substances. Starting from the left, the rising lines represent the heat

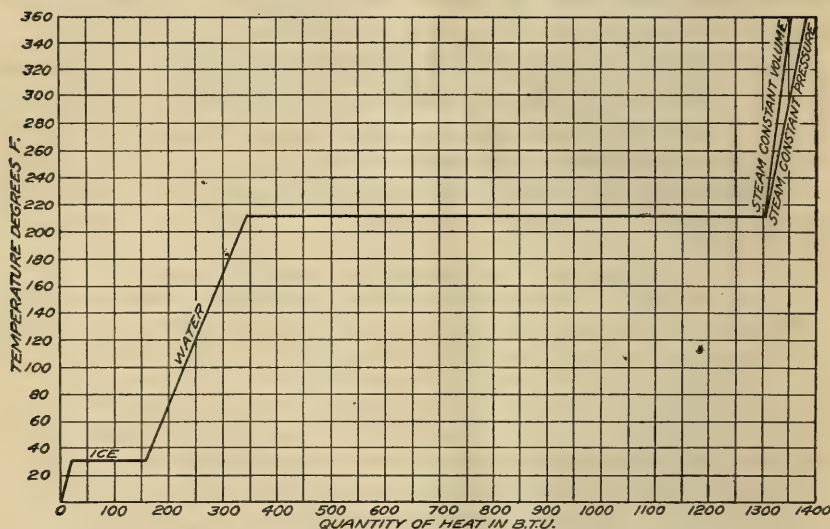


FIG. 9.—Diagram showing the relation of heat to temperature.

required to raise the temperature of the ice, water, steam at constant volume, and steam at constant pressure, respectively.

The same law applies to liquified anhydrous ammonia, carbon dioxid, and sulphur dioxid, which are the substances most commonly used in commercial refrigerating machines. These liquids are extremely volatile, their change of state takes place very rapidly, and their latent heat is absorbed at a corresponding rate. Their boiling point is sufficiently low under atmospheric or other conveniently produced pressure to give the temperature desired. Although the same principles underlie the use of all such fluids, their physical properties vary, and consequently demand different treatment in order to produce the best results.

The theoretical requirements of a good refrigerant are: A low boiling point at ordinary pressure, a large latent heat of vaporiza-

tion, and a small specific volume. A low boiling point is desirable, because it makes operation possible with comparatively low pressure in all parts of the system; therefore, the machines and accessories may be of lighter construction, with smaller loss of gas by leakage. As the latent heat of vaporization is, to a certain extent, a direct measure of the cooling effect, it is obvious that the greater the heat of vaporization the better the refrigerant. The specific volume of the refrigerating agent determines the volume of the cylinders of the compressor, consequently the size and weight of the machine.

In comparing the three refrigerating agents which are considered applicable to the dairying industry, viz, ammonia, carbon dioxide, and sulphur dioxide, it will be noted by referring to tables giving the main characteristics of the agents that, assuming the limits of operation are between 5° F. and 85° F., the absolute pressures are: Ammonia from 27 to 175 pounds, carbon dioxide from 290 to 1,000 pounds, and sulphur dioxide from 9 to 65 pounds. Taking the boiling points of the liquids at the temperature at which the liquid boils under atmospheric pressure, it will be noted that there is a wide difference in their boiling points as well as their latent heats of vaporization. Ammonia boils at 28.5° F. below zero and has a latent heat of vaporization of 572.8 B. T. U. Carbon dioxide boils at 110° F. below zero and has a latent heat of vaporization of 140 B. T. U. at a pressure of 182 pounds per square inch absolute. The latent heat at atmospheric pressure is not definitely known. Sulphur dioxide boils at a temperature of 14° F. and has a latent heat of vaporization of 162.2 B. T. U.

For practical purposes the value of a refrigerant depends upon its boiling point, its latent heat of vaporization, and upon the pressure at which it can be used.

To maintain a zero temperature with ammonia as the refrigerant an absolute pressure of 30 pounds per square inch is required in the evaporating coils; with carbon dioxide, 310 pounds absolute; and for sulphur dioxide, 10 pounds.

Ammonia has a much greater latent heat of vaporization and the working pressures are not excessive, but it has the disadvantage that it corrodes brass or any other copper alloy; consequently only iron or steel can be used in the construction of those parts of the machine with which the agent comes in contact. The pressures of carbon dioxide are so high as to cause trouble in keeping the stuffing box and joints tight. A relief valve is often placed in the high-pressure side of the system in order to protect it from excessive high pressures. It is noncorrosive, nonexplosive, and is not dangerous to life when diluted with air. The high pressures necessary, combined with the small specific volume of the gas, make it suitable for use with a very compact machine. As the lower pressure of

sulphur dioxid is below the atmospheric, any leakage of air will be into the system and will cause corrosion of the metal by forming sulphurous acid. The low pressures required in using sulphur dioxid as a refrigerant in connection with its large specific volume makes a large and cumbersome machine necessary. The ratios of the volumes of the cylinders necessary for a given capacity of machine, taking that of carbon dioxid as one, are approximately as follows: Carbon dioxid 1, ammonia 4.4, sulphur dioxid 13.

If either liquid ammonia, carbon dioxid, or sulphur dioxid is placed

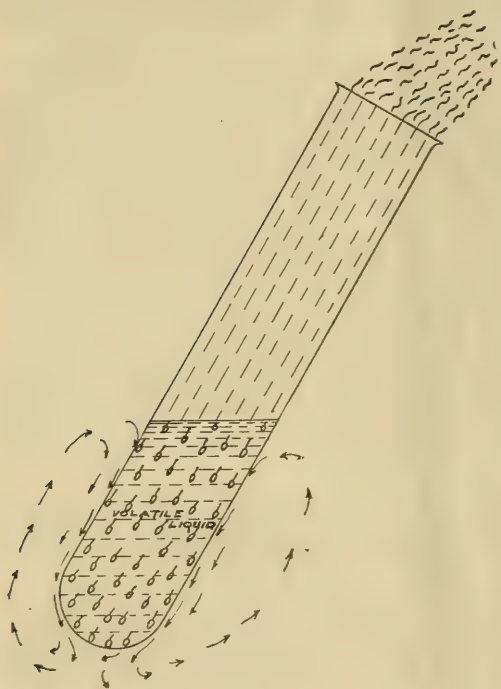


FIG. 10.

pressure below the ordinary temperature of the surrounding air, and the heat of evaporation will pass from the surrounding air directly into the refrigerant. The air, therefore, will be refrigerated or cooled, due to the fact that its heat is taken up by the boiling liquid. In other words, the heat required for the evaporation of the liquid is extracted from the air. At the boiling point the refrigerant will absorb a definite amount of heat from the air to effect the vaporization of a definite amount of the liquid, the heat being absorbed directly through the walls of the test tube from the outside air. There will be a circulation of air around the test tube, as indicated by the arrows in the figure, due to the greater weight of the cooled film of air lying next the surface of the tube which flows down and away from the bottom of the vessel, allowing the warmer and therefore lighter air to rise and take its place at the top. Figure 10 embodies the principle of the direct-expansion system of refrigeration explained in detail later.

If the test tube containing the refrigerant is immersed in a second vessel containing a solution of brine, as shown in figure 11, the evaporating liquid will absorb heat from the surrounding medium just as in the preceding case, but in this case the surrounding medium is brine instead of air and the heat required to effect the vaporization

of the liquid is absorbed from the brine, which in turn is absorbed from the air by the brine. In this case there is a double transfer of heat, viz, from the air to the brine and from the brine to the evaporating liquid in the test tube. The cooling effect is assisted by the circulation within the brine itself, due to the difference in weight of the colder liquid in contact with the surface of the test tube, and that at a distance from it. The colder brine sinks to the bottom of the vessel and its place is taken by the warmer brine, thus producing a circulation as indicated by the arrows, whereas in the preceding case the heat from the surrounding air was absorbed directly by the refrigerant. In view of the fact that it is impracticable to lower the temperature of the brine to that of the refrigerant, the absorption of heat from the surrounding air by the brine is not so rapid as when the air is in direct contact with the walls of the vessel as in the preceding case. Figure 11 embodies the principles of the commercial brine-storage system of refrigeration, which will be discussed later.

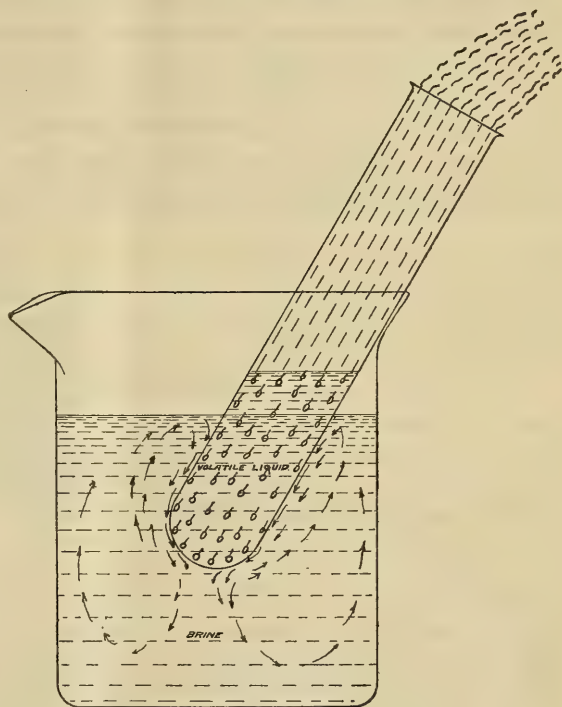


FIG. 11.

Going one step further toward the practical application of artificial refrigeration, imagine an arrangement as shown in figure 12, where the test tube in the foregoing illustration is replaced by a steel cask or drum, such as is commonly used for shipping ammonia, carbon dioxide, and other liquid gases, the tank corresponding to the beaker containing the brine. The liquid in the drum is under pressure, and if allowed to escape in a small stream through the throttling or expansion valve against atmospheric pressure it will evaporate in the coils located in the brine tank and the heat required for vaporization will be taken from the brine. If a pump were attached to the free end of the pipe the suction of the pump would tend to produce a vacuum, which action would accelerate

the evaporation of the liquid and the absorption of latent heat would go on faster than ever.

If it were not for the initial cost of the refrigerating medium this elementary form of refrigerating system, in which the refrigerant is allowed to escape to the atmosphere after evaporation, might find some commercial application, but as the refrigerants are expensive, such a system would be very costly to operate. Therefore, as the volatile liquids are valuable and can not be thrown away, if the reverse action takes place, that is, if the volatile gas is again converted into a liquid, it may be carried through the same cycle, over and over again indefinitely, and if it were possible to have no leakage one charge would be sufficient for all time.

REFRIGERATING MACHINES.

COMPRESSION SYSTEM.

In order to make the system illustrated in figure 12 commercially practical, it is necessary to provide some means for converting the

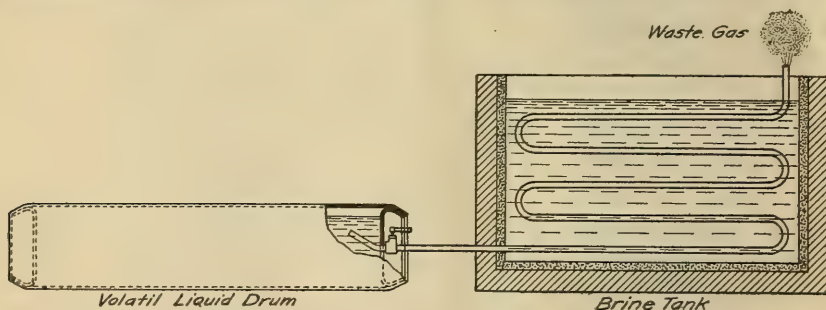


FIG. 12.

gasified refrigerant back into the liquid state in order that it may be again used for the purpose of absorbing heat. In other words, after the refrigerant has evaporated in the expansion coils and absorbed its fill of heat, much as a sponge sucks up its fill of water, the heat and water with which the refrigerating gas and sponge are respectively filled must be extracted before they can again perform the function of absorption. The water is forced out of the sponge by the simple application of pressure, but in the case of the refrigerating gas it becomes necessary not only to supply pressure, thereby raising the temperature of the gas by converting mechanical work into heat, but since the heat can be made to "flow" only from a relatively warmer to a relatively cooler substance, there must also be provided some cooling medium which will absorb the heat from the gas. Water being the cheapest and most convenient natural cooling medium, it is used almost entirely for this purpose.

Since the pressure and consequent temperature of the cold refrigerating gas returning from the expansion pipes must be raised before

the transfer of heat can be made to take place between it and the cooling water at ordinary temperatures, a compressor or a suitable gas pump must be used with a compression system of refrigeration. There must also be furnished a suitable cooling chamber or condenser in which the cooling water may be brought sufficiently near the refrigerating medium to allow the necessary heat to flow from the hot refrigerant to the cool water. Therefore the essential parts of a compression refrigerating system and their functions are:

A compressor, which is nothing more than a specially designed pump, which takes the gas from the evaporator coils and compresses it into the coils of the condenser, reducing the volume of the gas and increasing its temperature by changing work into heat.

A condenser, which consists of coils of pipe over which water is allowed to flow, or in some constructions the cooling water passes through an inner tube and the gas is discharged by the compressor into the annular space between the inner and the outer pipes. The heat imparted to the gas is given up to the cooling water, thereby liquefying the gas.

An evaporator, in which the liquid is allowed to boil and absorb heat from the surrounding media, again changing into the gaseous state. In other words, the process of refrigeration by means of the compression system is divided into three distinct stages, namely, compression, condensation, and expansion.¹

Compression.—The gaseous refrigerant is drawn into the compressor or pump and there compressed to a pressure dependent upon the refrigerant and the temperature and quantity of cooling water used in the condenser. The latent heat of the vapor, that is, the quantity of heat imparted to it to effect its vaporization from a liquid to a vapor is converted into active or sensible heat during this compression.

Condensation.—The vapor is forced into the condenser coils under high pressure by the compressor, where the nonactive and sensible heat developed during compression is absorbed by the cooling water, thus removing from the vapor the heat required to keep it in the gaseous state, and thereby reconverting it into a liquid at the temperature and pressure existing in the condenser.

Expansion.—The refrigerant, after being liquefied in the coils of the condenser, is passed first to a liquid receiver and then into pipe coils through a throttling or expansion valve which is capable of being adjusted to allow the liquid to pass in small quantities. As there is a materially lower pressure maintained in these pipe coils by the com-

¹ In order to make the compression system perfectly reversible there is, in addition to the three stages mentioned above, a fourth, which consists in the reduction of the temperature of the liquid from the condenser temperature to that of the refrigerator, by the vaporization of a part of the liquid and by doing work by moving a piston.

pressor or pump, the liquefied refrigerant again expands into a vapor after passing into the coils, taking up from whatever substance surrounds it an amount of heat exactly equal to that which was given up during condensation. The vapor is again drawn back into the compressor, compressed, condensed, and expanded, the cycle of operation being repeated indefinitely with the same refrigerant.

Figure 13 presents diagrammatically the essential members of a compression-refrigerating system, in which *A* represents the direct expansion coils, in which the refrigerant is expanded after leaving the expansion valve *E*; *B*, the compressor or pump, which takes the warm gas or vapor from the expansion coils *A* and compresses them into the condenser *C*; *C*, the condenser for cooling and liquefying the gasified refrigerant; *R*, the receiver, into which the liquefied refrigerant flows from the condenser; *E*, the expansion or throttling valve, which controls the flow of the liquid refrigerant from the receiver *R* to the

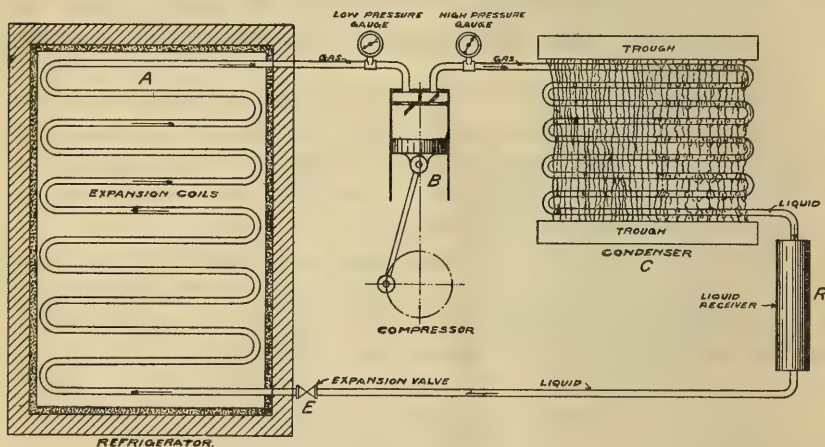


FIG. 13.—Elementary diagram of direct expansion system.

expansion coils *A*, where a materially lower pressure is maintained by the compressor, which causes the liquid to boil at a temperature sufficiently low to absorb heat from and therefore refrigerate the surrounding air.

In practice, however, the system is more elaborate, as will be noted by referring to figure 14, which shows a complete compression-refrigerating plant with all the accessories necessary for its operation.

DIRECTIONS FOR INSTALLING, CHARGING, AND OPERATING INCLOSED TYPE OF AMMONIA COMPRESSION MACHINES.

INSTALLING.

The compressor, condenser, and receiver should be located in a dry and well-lighted place where they will be accessible at all times for inspection and repairs. The liquid receiver and connections

should not be placed in the engine or boiler room, as the heat will evaporate part of the liquid and drive gas back into the condenser to be recondensed. Such an arrangement makes it necessary to install a larger condenser and to use more condensing water, and, in addition, the liquid goes into the evaporating system carrying its full quota of heat, thereby reducing its value.

The machine should be set on a well-built brick or concrete foundation, care being taken to have the machine perfectly level.

Before making the pipe connections all dirt and scale should be removed from the inside of the pipe and a pipe die run lightly over all threads exposed during shipment, after which they should be thoroughly washed with gasoline or benzine. The pipe fittings should be cleaned in the same way before connections are made. After the pipe and fittings have been thoroughly cleaned, apply a paste of litharge and glycerin to the threads and screw the pipe fittings up tight. Where soldered joints are required the threads on the pipe ends and fittings should be heated and thinned with solder before they are made up.

When the machine is in place and all pipe connections properly made, remove the cover of the crank case and fill with ammonia oil to the level of the crank shaft, or to the line on the frame of the compressor indicating the proper amount of oil required.

Disconnect the by-pass piping and close the main suction and discharge valves. Run the machine under no-load conditions for two hours to smooth up the bearings and make any adjustments that may be found necessary; then connect the by-pass on the discharge side. (Some manufacturers provide plugs in the by-pass piping, in which case it is not necessary to disconnect the piping.) Open the main discharge valve and all other valves on the ammonia system except the main suction valve and the by-pass valves, which should be closed.

Now start the machine again and pump air on the entire system to a pressure of about 150 pounds on the low-pressure gage. This should not be done, however, in one operation, on account of the possibility of melting the joints, due to the heat contained in the air. During the operation the machine should be stopped from time to time and all the apparatus examined in order to see that no undue heating occurs. Should parts of the apparatus be found unduly hot, the machine should remain at rest until the heated part is sufficiently cooled. Stop the machine and examine all piping and connections for leaks. This can best be done by applying soapsuds with a brush to all connections, and if there are any leaks they will be indicated by bubbles. If there is an ice-freezing tank in connection with the system, run water into the tank, completely submerging the coils,

and if there are any leaks they may be detected by air bubbles rising from the joints.

If the ammonia system has been found to be tight at the pressure of 150 pounds, close all expansion valves and again start the machine and pump air to a gage pressure of about 275 pounds, unless the discharge pipe gets very hot. As the low-pressure gage will not register so high a pressure as 275 pounds, it should be cut off when it has reached the limit of its scale. Allow the system to remain under this pressure for several hours and if the loss in pressure as shown by the gage, does not exceed 5 pounds, the system may be considered satisfactory so far as leakage is concerned.

Remove the short pieces of pipe between the suction valve and the machine and allow the air under pressure to escape quickly through the suction valve. Any dirt and scale that may be in the piping and which would otherwise be drawn into the machine with the suction gas will be blown out.

Before the system is charged with the refrigerant it is necessary to remove all air and moisture; otherwise the efficient operation of the machine will be seriously interfered with. Manufacturers usually provide special valves for discharging the air from the system, which is accomplished by starting up the machine and pumping the air out, the operation being just the reverse of that when working under service conditions. When a vacuum of about 26 inches has been obtained, stop the machine again and allow it to stand for several hours in order to determine if the system will maintain a vacuum. If the vacuum is maintained, the system is ready to be charged with the ammonia.

It is impossible in some cases to remove all the air from the system by means of the compressor, in which case it is desirable to insert the proper amount of refrigerant gradually. Often from 60 to 70 per cent of the full charge is inserted, and the air remaining in the system is allowed to escape through the purgecocks on the condenser until the ammonia shows, which will be detected by the very strong odor, and the escaping vapor will have the appearance of steam. An additional quantity of ammonia should then be inserted. This should be repeated once or twice a day until all the air has been displaced and the complete charge has been introduced.

CHARGING.

To charge the machine, a drum of anhydrous ammonia is connected by a suitable pipe to the charging valve on the liquid receiver. Allow ammonia to enter the system through the charging valve until a pressure of about 15 pounds is recorded on the gage and then turn on the condensing water and start up the machine slowly at first.

The suction and discharge valves should be wide open while the machine is being charged. When one tank is emptied the charging valve should be closed and another tank placed in position, this being repeated until the system is sufficiently charged for work, when the charging valve should be closed and the main expansion valve adjusted. The ammonia drums should be weighed before and after being emptied or partially emptied, and a record kept of the amount necessary for charging. The glass gage on the liquid receiver will show the amount of liquid contained, and the pressure gages, as well as the gradual cooling of the brine in the refrigerator and the frost collecting on the expansion pipe, will indicate when a sufficient amount of the refrigerant has been inserted to start working.

OPERATING.

After the machine has been started and the expansion valve adjusted, the temperature of the delivery pipe should be carefully noted, and should a tendency to heat be observed, the expansion valve should be opened wider, while, on the other hand, if it should become cold, the valve should be slightly closed, the adjustment being continued until the temperature of the pipe is the same as that of the cooling water leaving the condenser. If there is an insufficient charge of the refrigerant, the delivery pipe will become heated, even though the expansion valve is wide open.

Some of the signs which indicate the proper working of the plant, other than the fact that it is satisfactorily performing its refrigerating functions, are: The vibrations of the pointers on the high and low pressure gages; the frost on the exterior surface of the refrigerating pipes; the liquid refrigerant can be plainly heard passing through the expansion valve; and the difference in temperature between the liquid leaving the condenser and the final temperature of the cooling water, and between the refrigerator and the brine.

Should it become necessary to disconnect any part of the ammonia system for any reason, the ammonia must be pumped out of that part and stored in another part of the system. After making repairs, all the air must be exhausted from that part of the system before the ammonia is again allowed to enter.

To pump ammonia out of the condenser.—Close valves in the liquid pipe, the main suction, and discharge valves, and open the by-pass valves after draining the water from the condenser to prevent freezing and bursting of the pipes. Start the machine and pump out the ammonia until a partial vacuum is indicated by the high-pressure gage; then stop the machine and allow it to stand for two or three hours in order that any liquid ammonia lying in the pipes may have time to evaporate. Start up the machine again and pump down to a 25-inch

vacuum. After all ammonia has been exhausted from the system, close the valve in the ammonia discharge pipe and the condenser may then be disassembled.

To pump the air out of condenser.—The main suction and discharge valves should remain closed. The by-pass valve on the discharge side must be open and the one on the suction side closed. Manufacturers provide some means of opening the by-pass piping, either by a pipe tee or some form of cock; this should be opened and the machine run until all air is exhausted from the condenser. After all air has been exhausted the opening in the discharge by-pass must be closed and all valves set as they were originally. Ammonia may now be allowed to reenter the condenser, and after turning on the cooling water the plant is again ready for operation.

To pump ammonia out of cold-storage room or cooler coils.—All expansion valves must be closed, also the suction stop valves, except the suction stop valve on the coil which it is desired to pump out. This valve must be left open and the machine run until a 10 or 15 inch vacuum is obtained, when the machine should be stopped for two hours in order to allow any remaining liquid in the coils to evaporate. After the evaporation of the remaining liquid, start the machine again and pump down to a 25-inch vacuum. If all liquid has evaporated and the ammonia valves are tight, the coils should maintain the 25-inch vacuum until broken. The suction and discharge valves on the machine may now be closed and the part of the system which has been pumped out may be opened with safety.

To pump air out of storage rooms or cooling coils.—See that the main discharge stop valve is closed and remove the plug from tee or open cock, as the case may be, in the by-pass just below the discharge stop valve. The machine should be started slowly and run until all the air is exhausted from the coils, then stop machine and replace plug in tee or close cock in the by-pass.

To pump out compressor.—The same method as above is followed, except that the suction stop valve only is closed, as no part of the system except the compressor is to be pumped out.

CARE OF REFRIGERATING MACHINERY.

In caring for machinery of any kind, one of the most important things is cleanliness, and especially is this true of refrigerating apparatus. If the cooling and condensing surfaces are allowed to become coated even slightly their heat-transferring efficiency will be lowered materially.

Where atmospheric condensers are used it is an easy matter when the surfaces become coated to clean them with a brush, provided the coating is not of the nature of a scale. If the substance is hard, it will be necessary to employ files or steel scrapers in removing the

scale. In double-pipe condensers and coolers it is not such an easy matter to clean them as it is necessary to take off a return bend from the end of the condenser or cooler in order to examine or clean them. This should be done frequently, and if the inner pipe is found to be coated with a soft substance it can be removed by the aid of an ordinary flue brush. If, however, the coating is in the form of scale, it will be necessary to bore it out on a lathe or tube-boring machine.

The life and satisfactory operation of all mechanical apparatus are dependent on proper care as well as on the original design. It is therefore necessary that such apparatus should receive frequent and careful inspection and prompt correction of all defects found. As cleanliness is essential for the satisfactory operation of machinery of all kinds, the wearing parts of the machine should be kept free from dirt and grit and the oilways open, well lubricated, and adjusted. The clearance of the pistons should be adjusted to a minimum, both in the steam and compressor cylinders.

In operating an ammonia plant the gages should be carefully watched, as they are the indicators of the work being done. The

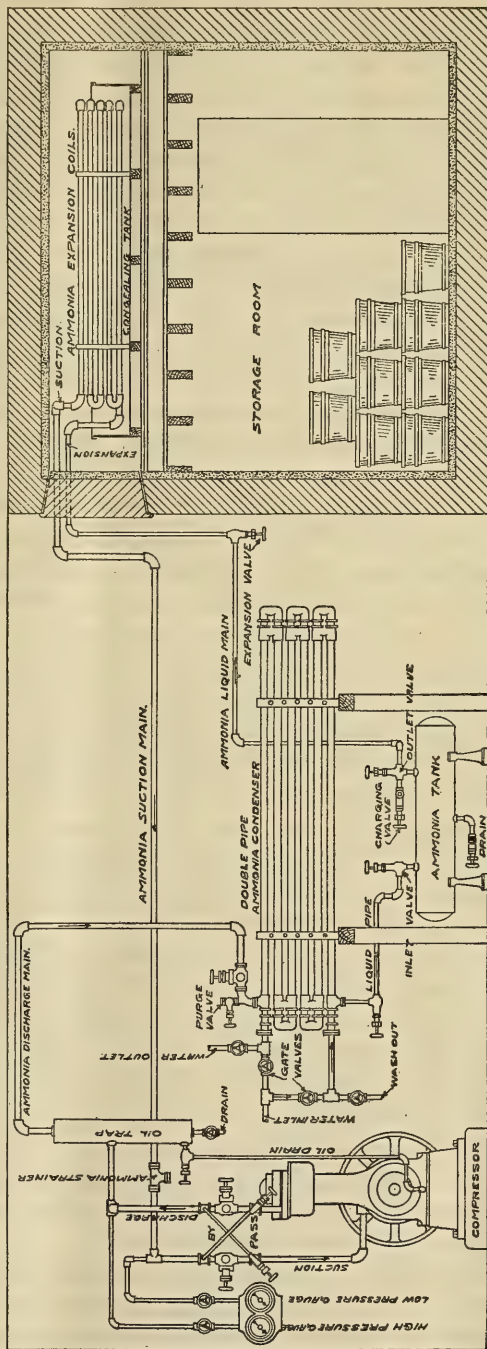


Fig. 14. — General arrangement of compression refrigerating system.

suction or low-pressure gage is controlled to a great extent by the expansion valve in the liquid line; consequently opening it will increase the low pressure, as the more the valve is opened the more gas will be pumped, providing the machine is run at a constant speed. If the speed of the compressor is increased, the amount of work will be proportionately increased provided the valves are large enough to handle the additional amount of gas, and vice versa. If the expansion valve is opened too wide for the speed at which the machine is running, the suction pipe will frost back to the machine and even the top of the compressor may become covered with frost. For satisfactory operation in a refrigerating plant a slight frost should cover the suction pipe close to the machine.

If the temperature of the brine in the cooling room is high, a corresponding high back pressure should be carried, and, on the other hand, a low brine temperature requires a low back pressure. Should a very low brine temperature be required, in addition to a low back pressure, the machine should be run at a faster speed, depending upon the relative capacity of the machine and the work to be done. It is necessary in the maintenance of low temperatures to keep the system free from air and deleterious gases, and plenty of cooling water should be supplied to the condenser while the plant is in operation.

For small plants the receiver should be of suitable size to hold all the refrigerating medium in a liquid form. It is usually located just below the condenser, or as near to it as local conditions will allow, so that the liquefied gas may return to the receiver by gravity.

In order that the amount of refrigerant contained in the system may be seen at a glance, the receiver should be provided with a glass gage similar to that placed on steam boilers to show the amount of water. This is especially true in small plants, where the attendant may not have had the necessary experience to enable him to judge of the amount of refrigerant in the system, and by observing the line of the liquid in the glass gage each time before starting up the compressor he will be able to note any loss of the refrigerant which he might not be able to do by other methods.

Some manufacturers, however, object to placing a gage of this kind on the receiver, as they contend that there is a possibility of loss of refrigerant by the breaking of the glass, and perhaps some danger should anhydrous ammonia be the refrigerant used. There is little danger, however, as the pressure and temperature is nearly constant and automatic ball stop valves may be used that will shut off the flow should the glass break.

It should be distinctly understood, however, that the foregoing refers to new plants and not to old ones. Under no circumstances should air at high pressure be pumped directly into an old system after repairing, or into one that has been standing idle for some time,

as an explosion is likely to occur, due to the vaporization of oil which may have lodged in the coils. The temperature of the air, when pumped into the system at a high pressure, is liable to exceed the flash point of the oil, resulting in an explosion.

For the same reason it is also dangerous, especially in the case of small, fast-running machines, to allow too much air to enter when pumping out the compressor in case it becomes necessary to pack the stuffing box; for should the attendant neglect to purge the condenser after the operation, the air in the system will be carried along with the ammonia gas, necessitating a higher pressure and a consequent higher temperature than would otherwise be attained; and should the temperature in the system get too great, there is danger of the oil which may be deposited in the coils reaching a point where flash-ing will take place, which will result in an explosion.

In small installations usually found in milk plants, cream-eries, and dairies the condensers are of

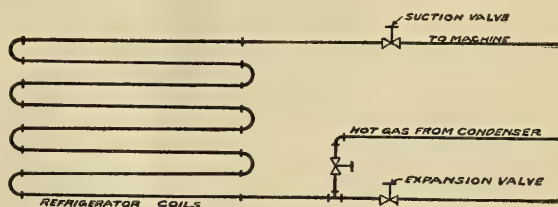


FIG. 15.—Conventional diagram.

small dimensions; consequently, they can not hold large quantities of excess air. Hence great care should be taken to thoroughly purge the system of air when starting up after pumping out the compressor by blowing the air from the system. Manufacturers provide cocks for this purpose.

In cleansing old plants or those that have been shut down for some time from deposits of oil, it is a good plan to pump hot ammonia gas into the system. The gas should be taken from the line just before it enters the condenser. If taken from the top of the condenser, the gas will probably contain air and other impurities which would be liable to cause an explosion.

Referring to the conventional diagram, figure 15, the method of operation should be as follows: Connect a temporary pipe line with valve from the lowest part of the condenser or to the pipe line just before entering the condenser. Close the expansion valve and pump hot ammonia gas into the coils. Have the suction valve opened slightly and occasionally open it wide quickly to allow the oil to be carried out and deposited in the oil trap, from which it can be drawn off.

Before starting up the plant care should be taken to see that all oil cups are filled and the oil ways open, in order that all wearing surfaces may be well lubricated before the machine is started.

To start.—(1) Turn the water on the condenser and water jacket, and open the discharge valve on the compressor; (2) start the machine slowly at first and after the machine is in motion and the pressures are at proper point open the suction valve on the compressor gradually; (3) open the expansion valve sufficiently to give the required back pressure and the machine is in full operation.

To stop.—(1) Close the king valve which is between the receiver and the expansion valve and pump the low pressure to zero. This is considered better practice than closing the expansion valve each time the machine is stopped, thereby necessitating readjustment of the expansion valve upon starting up again; (2) open all drips and

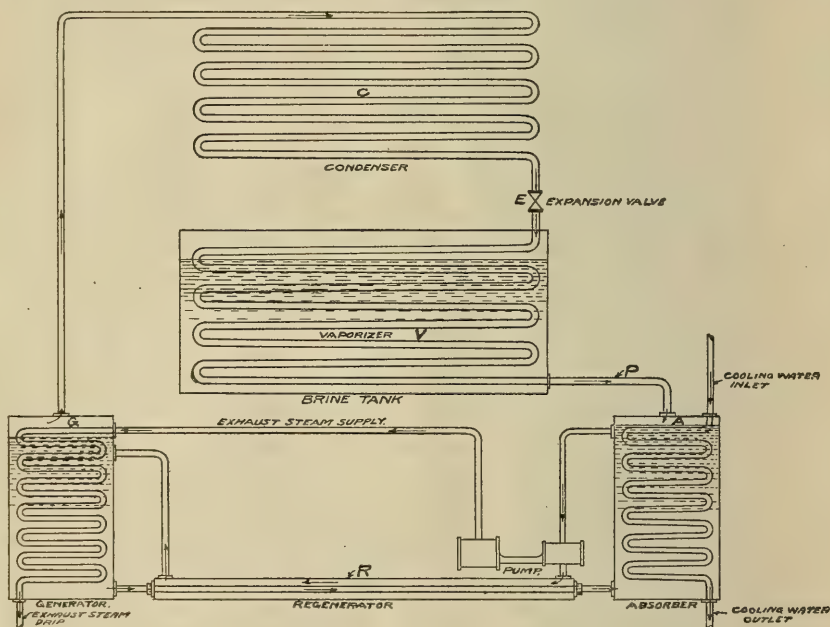


FIG. 16.—Elementary diagram of absorption system.

drains and shut down the machine; (3) close the suction and discharge valves, and all oil cups and water valves; (4) clean the machine thoroughly and examine all bolts and nuts to see that they are tight and see that the bearings are properly adjusted.

VAPOR ABSORPTION SYSTEM.

The absorption and expulsion of ammonia gas by water forms the basic principle of the absorption process of refrigeration.

By referring to the elementary diagram, figure 16, the principles of this system of refrigeration will be understood. The generator *G* is an inclosed vessel which is partly filled with a solution of ammonia gas in water, under high pressure. Heat is applied to the generator,

usually by allowing low-pressure steam to flow through coils of pipe located in the generator, as indicated in the diagram, and the ammonia gas is driven off under pressure through the pipe into the condenser *C*, where it is condensed to a liquid when cooled by the condensing water. The ammonia, now in a liquid state, flows through the expansion valve *E* into the vaporizer *V*, where it is evaporated, the heat required for its evaporation being absorbed from the brine surrounding the coils. The vaporization of the liquid ammonia is made possible by the low pressure which is maintained in the evaporator due to the rapid absorption of the anhydrous ammonia by the weak aqua ammonia in the absorber. The brine is circulated about the coils of the vaporizer and from thence through the coolers, where it in turn absorbs heat from the goods in storage. The vaporizer coils may, however, be located directly in the compartment whose temperature it is desired to lower, in which case it is termed a direct expansion system. From the vaporizer the ammonia, now in the gaseous state, flows through the pipe *P* into the absorber *A*, which contains a weak solution of ammonia. The absorption of the ammonia gas by the weak solution in the absorber generates heat, which is carried off by the cooling water which is circulated through coils located in the absorber. The strong liquor thus formed in the absorber is delivered to the generator by a pump through the outer space in the regenerator coil *R*. The weak liquor from the generator is transferred to the absorber through the inner coil of the regenerator; consequently the liquid entering the generator is thus heated while that entering the absorber is cooled. The function of the regenerator is, therefore, to economize heat by transferring the heat from the weak to the strong liquor. The weak liquor coming from the generator, where it has been subjected to heat, goes into the absorber, where it is cooled by means of water circulation. The reverse is true in the case of the strong liquor; that is, the strong liquor comes from the absorber, where it has been cooled by water circulation, and goes into the generator, where it is heated. It is obvious that any heat transferred from the weak to the strong liquor represents just so much gain in economy.

As the only power required by the absorption system is that necessary to circulate the various liquids, it is inconsiderable when compared with that required by the compression system. Usually the exhaust steam from the pumps furnishes sufficient heat from the operation of the plant. The amount of cooling water, however, required by this system is greatly in excess of that required by a compression plant of the same capacity.

In practice, however, the vapor-absorption system of refrigeration is more complicated than shown in the elementary diagram. Figure

17 illustrates a general arrangement of a plant of this character with all the necessary accessories.

OPERATING ABSORPTION MACHINE.

To start.—(1) Start water circulating through machine; (2) start brine pump, making sure that the brine is circulating through cooler; (3) turn steam on gradually (steam should never be shut off entirely); (4) open gas line between cooler and absorber; (5) open weak-liquor valve, setting it at the usual running position; (6) start ammonia pump; (7) when generator pressure is about that usually carried, open valve in the dry gas line slowly, allowing the gas to enter the condenser; (8) open and set expansion valve.

To stop.—(1) Close steam valve on generator almost entirely (steam should never be shut off entirely); (2) close expansion valve; (3) shut down ammonia pump; (4) close weak-liquor valve; (5) shut

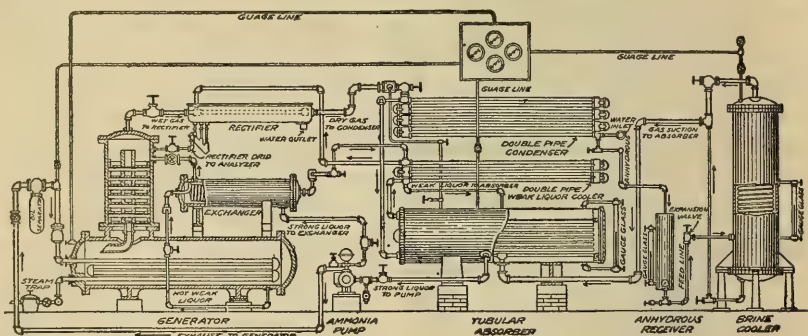


FIG. 17.—General arrangement of absorption refrigerating machine.

off cooler and absorber gas line; (6) close valve in dry gas line to condenser; (7) shut down brine pump; (8) shut off water supply.

The foregoing suggestions are of a general nature only and should be considered as such. The purpose for which a plant is used and the character of the trade supplied have considerable bearing on its operation and management; consequently the engineer in charge must determine on the best methods to employ in order to get the best results.

Figure 18 is intended to show, diagrammatically, the apparatus which is common to both the compression and absorption systems of refrigeration. As a matter of fact there are a number of accessories required in both systems for their successful operation which are not shown in the elementary diagram, as will be noted by referring to figures 14 and 17, which show the complete equipment of the two systems.

METHODS OF UTILIZING REFRIGERATION.

There are two distinct methods of utilizing refrigeration, namely, the direct expansion system and the brine system.

DIRECT-EXPANSION SYSTEM.

The coils of pipe in which the refrigerant is evaporated or expanded are placed directly in the room to be cooled; the heat necessary for the evaporation of the liquid refrigerant is, therefore, absorbed directly from the air, or whatever substances surround the tubes. The diagrammatic arrangement in figure 19 shows, in an elementary form, the commercial direct-expansion system. With a system of this kind the work of refrigeration practically ceases as soon as the plant is shut down; consequently it becomes necessary, in

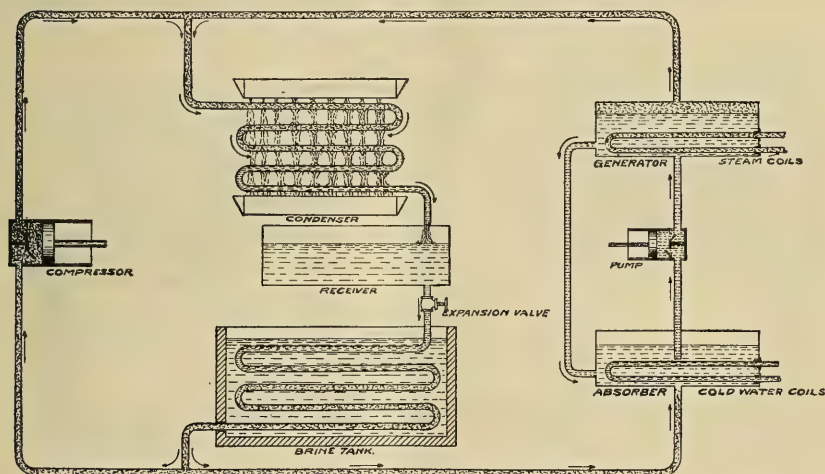


FIG. 18.—Diagrammatic arrangement showing equipment common to both the compression and absorption systems of refrigeration.

most cases, to run the plant continually or take the risk of losing the goods in storage.

For economical operation the suction pressure and evaporating temperature should be as high as possible. The suction pressure is governed by the temperature desired in the refrigerator. In milk plants, creameries, and dairies the suction pressure with an ammonia system should be about 15.67 pounds gage and a consequent gas temperature of 0° F.

Take, for example, a creamery cold-storage room 10 by 10 by 10 feet inside dimensions, which is of sufficient capacity to hold a week's output of butter from a creamery making 2,000 pounds daily. For the sake of simplicity, only the storage of butter is considered. It is assumed that the average outside temperature of the room is 75° F. and the inside temperature is to be maintained at 32° F. while the

machine is in operation. It is further assumed that the walls, floor, and ceiling are insulated for a heat transmission of 2 B. T. U. in 24 hours per square foot per degree difference of outside and inside temperature of room. The butter will come from the churn at about 58° F.

B. T. U.

The heat that will come through the insulation is $600 \times 2(75-32) = 51,600$

The heat to be removed from butter is $2,000 \times 0.5494(58-32) = 28,574$

 80,174

Allowing 25 per cent to cover the additional work required for opening doors, lights, etc., we have a total of, say, 100,000 B. T. U. in 24 hours.

Assuming a back pressure of 15.67 pounds, which is equivalent to zero temperature ammonia, and a difference of temperature between

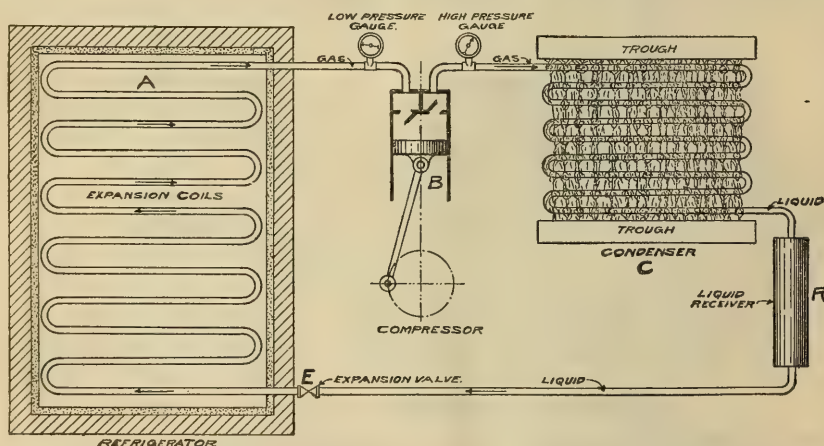


FIG. 19.—Elementary diagram of direct expansion system.

the refrigerant inside the piping and the layer of air surrounding the same of 10° F., and that 1 square foot of pipe surface will absorb about 10 B. T. U. per hour for each degree of difference between the inside and outside temperature of the pipe, the number of linear feet of 1½-inch direct-expansion piping required for the room, is

$$\frac{100,000 \times 2.3}{24 \times 10 \times 10} = 96, \text{ or } 10.4 \text{ cubic feet of room space for each linear}$$

foot of piping. With the direct-expansion system the work of refrigeration practically ceases with the shutting down of the machine. The frost which has collected on the piping itself will tend to keep the room temperature down for a short time, but this is so small that it may be disregarded; consequently, it is necessary to run the direct-expansion plant continuously in order to maintain low temperatures.

BRINE-CIRCULATING SYSTEM.

In this system the coils of pipe in which the refrigerant is expanded are located in a tank or specially designed brine cooler containing a solution of common salt, or calcium chlorid, of sufficient density to insure a low freezing point. After the brine has been reduced to a low temperature by the transfer of its heat to the expanding refrigerant, it is pumped through coils of pipe located in the room to be cooled, absorbing from the atmosphere a good part of its heat. It is then returned to the brine tank, or brine cooler, where it is recooled and again circulated through the rooms.

While the direct-expansion system is simple to operate, less expensive to install, and more efficient from the standpoint of heat transfer, nevertheless in the operation of small plants, applicable to the dairy industry where the plant proper is operated perhaps six or eight hours per day, it is more economical to install a brine system, in order

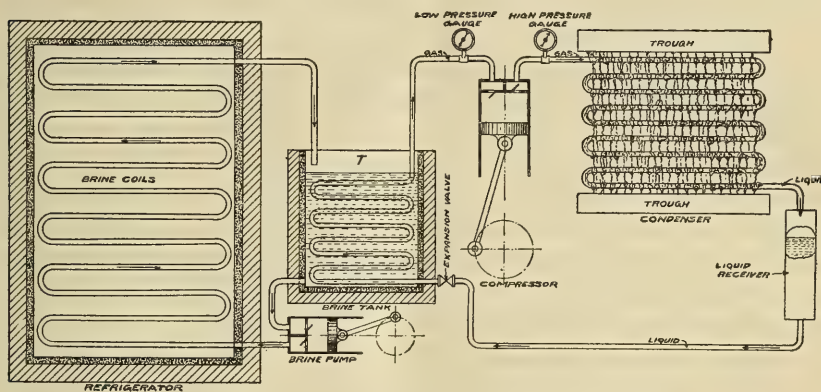


FIG. 20.—Elementary diagram of brine circulating system.

that some work of refrigeration may go on after the plant is shut down for the day, or in case of accident to the machinery. It is only necessary in the brine-circulating system to operate the brine pump for forcing the brine through the coils. The principles of this system are illustrated in figure 20. In addition to the usual members shown in the direct-expansion system, this system employs a brine tank, a series of brine coils, and a brine pump for circulating the brine through the coils. The cooling effect of the evaporating refrigerant is expended in the brine in this case, instead of directly in the cooling room, as indicated in the direct-expansion system, and the brine is circulated by the pump through the brine coils located in the cooling room. It should be borne in mind, however, that there is a double transfer of heat which cuts down the efficiency of the system to a certain extent, namely, from the air in the cooling room to the brine and from the brine to the expansion coils. The initial

cost of installing the brine-circulating system is more than that of the direct expansion, as it includes, in addition to the members of the direct-expansion system, a brine tank, brine coils, and a brine pump. The power necessary to operate the brine pump must also be considered. The excess power required for the operation of the brine-circulating system over that of the direct expansion of the same capacity is that necessary for pumping the brine from the tank through the cooling coils back to the tank; that required to overcome the friction of the brine in the pipes in traversing the above cycle; the additional refrigeration necessary to make up for the heating effect produced mechanically by circulating the brine, and the heat absorbed through the brine tank and through the brine piping; that required to make up for the reduced efficiency by having to operate the plant at a back pressure sufficiently low to obtain a correspondingly low temperature in the evaporator coils to compensate for the second heat transfer encountered between the air in the cold-storage room and the refrigerant.

The average difference in temperature between the circulating brine inside the piping and the surrounding air is, of course, much less than is the case when the refrigerant is expanded directly in the piping located in the cooling room, assuming the back pressure on the machine is the same in both cases. The difference in temperature between the refrigerant and brine depends on the insulation of the brine tank, piping outside of the rooms, etc., and as this varies between wide limits it is impracticable to calculate the amount of brine piping very closely on the basis of heat transfer, as was done in the case of direct expansion; consequently it is the common practice to install from one-half to twice as much brine piping in the brine-circulating system as would be used if direct expansion were employed. This allowance, however, is very liberal and is made to cover unfavorable cases where the insulation is poor; and further, any surplus piping serves to increase the efficiency of the plant.

Allowing 50 per cent more brine than direct expansion piping we have $96 \times 1.50 = 144$ linear feet of $1\frac{1}{4}$ -inch piping required to do the same work as the direct expansion, or 7 cubic feet of storage space per linear foot of pipe. This amount of piping, when filled with brine, will contain 1.5 cubic feet. During the night the average difference in temperature between the inside and outside air will be about 43° F., therefore the heat that will come through the 600 square feet of surface of the room during 16 hours' shut-down period will be
$$\frac{600 \times 2 \times 43 \times 16}{24} = 34,400 \text{ B. T. U.}$$

If the initial temperature of the brine during the shut-down period is 16° while the final is 32° , giving a rise of 16 degrees, the heat that will be absorbed by the 1.5 cubic feet of brine contained

in the piping will be $1.5 \times 52 \times 16 = 1,248$ B. T. U. Consequently the hold-over period due to the brine in the piping is $\frac{1,248 \times 16}{34,400} = 0.58$ hour. If there are 2,000 pounds of butter stored in the room, it will also assist in increasing the time of shut down for a 3-degree rise in room and contents. The rise in temperature of the butter for a 16-hour shut down will be $\frac{34,400}{2,000 \times 0.5494} = 31.3$ degrees, or 3 degrees in 1.53 hours. Therefore, the total time the plant can be shut down for a 3-degree rise in temperature of room and contents is $0.58 + 1.53 = 2.1$ hours. Consequently it becomes necessary with this system to circulate the brine continuously. If, however, a sufficient volume of low-temperature brine is available for circulating through the coils, the refrigerating machine may be shut down for

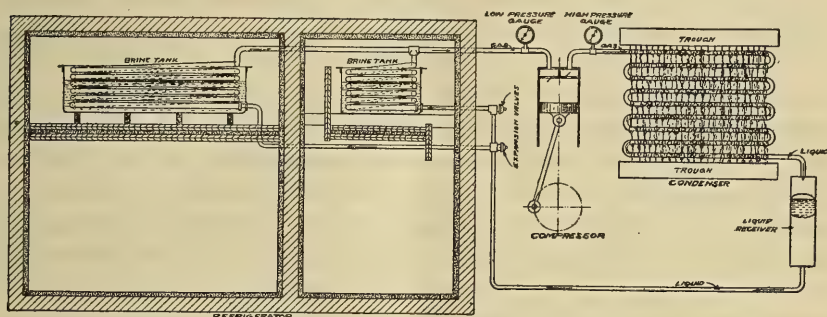


FIG. 21.—Elementary diagram of brine storage system.

a time, depending on the volume and temperature of the brine, by continuing the action of the pump.

BRINE-STORAGE SYSTEM.

In place of the continuous brine coils employed in the brine-circulating system there is a modified brine system designed to give practically the same results (fig. 21). This is known as the brine-storage system and consists in replacing the main tank by several smaller ones located in the various compartments of the cold-storage plant. With an equipment of this kind the initial cost of the brine pump, the main brine tank, the necessary piping for brine circulation, and the brine-tank insulation are eliminated, as well as the power to operate the brine pump and the radiation losses through the brine tank and pipe insulation.

The heat-absorbing surfaces of the various small tanks entirely replace those of the brine coils. In practice, however, from one third to two-thirds of the direct expansion coils are placed outside of the brine, in direct contact with the air in the cold-storage room, in

order that the room may be cooled more quickly when the plant is started after being shut down for several hours, the remaining one-third or two-thirds, as the case may be, being submerged in the solution of brine.

Allowing a 3° rise in temperature of the air inside the room (32° to 35°) and a rise of calcium chlorid brine of 16° (6° to 22°), and as a cubic foot of brine will absorb about 52 B. T. U. per degree rise in temperature, the heat absorbed by the brine per cubic foot will be $52 (22-6) = 832$ B. T. U. The volume of brine necessary to hold over temperature under the foregoing conditions will then be $\frac{34,400}{832} = 41.3$ cubic feet, or 1 cubic foot of brine for each 24.2 cubic feet of room space. In other words, the heat that will be absorbed by the 41.3 cubic feet of brine for a 16-degree rise will be $41.3 \times 52 \times 16 = 34,362$ B. T. U. Therefore, the hold-over period due to the brine is $\frac{34,362 \times 16}{34,400} = 16$ hours. The 2,000 pounds of butter in storage will hold the temperature for 2.1 hours for a 3-degree rise in the room temperature. Consequently the total hold-over period due to both the brine and the butter will be $16 + 2.1 = 18.1$ hours, or for a 16-hour shutdown the rise in room temperature will be 2.6° . During the hold-over period the average temperature difference between the air and the brine is about 19° F., and with a coefficient of heat transmission through the walls of the brine tanks of 1.5 B. T. U. per square foot per hour per degree difference in temperature of the brine and air, the effective square-foot surface of the tanks should not be less than $\frac{34,400}{16 \times 19 \times 1.5} = 75$; say two tanks 8 feet long, 1 foot wide, and $2\frac{1}{2}$ feet deep.

One linear foot of $1\frac{1}{4}$ -inch pipe when submerged in still brine will absorb about 4 B. T. U. per hour per degree difference in temperature between the inside and outside of pipe, and as this difference is about 13.5° , the amount of $1\frac{1}{4}$ -inch submerged piping required is $\frac{51,600}{8 \times 13.5 \times 4} = 117$ linear feet, or 58.5 feet per tank.

This method, however, is only a compromise between the brine-circulating and the direct-expansion systems, but has been found satisfactory and compares very favorably with the brine-circulating system of the same capacity. When used for holding over temperatures when the plant is shut down, either in case of breakdown of machinery or to avoid keeping an experienced attendant on duty continuously, the tank system for small plants possesses advantages over either the direct-expansion or brine-circulating systems.

CONGEALING-TANK SYSTEM.

There is in use a modification of the brine-storage system known commercially as the "congealing-tank system." The principal advantage of this system is that by using a weak solution of brine a greater amount of refrigeration per cubic foot of brine is obtained by freezing a portion of the brine on the direct-expansion coils. This method, however, is not so efficient as the brine-storage system, due to the fact that the ice formed around the coils acts as an insulation. But the advantage gained in being able to store a greater amount of refrigeration in a small space often makes it advisable to install this system. In the operation of the congealing-tank system care should be taken not to let the volume of brine in the tanks freeze solid, for during the hold-over period some of the brine ice will melt, leaving a space between the ice and the sides and bottom of the tanks, and when starting up the refrigerating machine the smaller space between the ice and sides of the tanks will freeze first; consequently when the larger volume of brine at the bottom freezes the sides of the tank will be bulged out, due to the expansive force of the freezing brine. Therefore, ample space between the coils and sides of the tanks should be provided in order to allow the requisite amount of brine ice to form around the pipe coils at a safe distance from the sides. When a part of the brine solution is to be frozen, the volume of brine required is necessarily less than that required for a brine-storage tank system of the same capacity. In practice about one-half the volume of the brine storage is allowed for the congealing-tank system. Therefore the case under consideration will require two tanks 8 feet long, $2\frac{1}{2}$ feet deep, and 6 inches wide. The effective surface of the two tanks is 93 square feet. The heat absorbed by each square foot of surface per hour during shutdown period is $\frac{34,400}{93 \times 16} = 23.1$ B. T. U. Taking the coefficient of heat transmission in B. T. U. per degree difference in temperature as 1.5 per square foot per hour, the temperature difference necessary between the brine and air is $\frac{23.1}{1.5} = 15.4^\circ$.

With a 15 per cent solution, by weight, of common salt the freezing point is 12.2° F. Then the temperature of brine at the time the plant is shut down will be 12.2° , and at the time of starting up 27.6° . One cubic foot of the brine will absorb 59.2 B. T. U. per degree rise in temperature, and for a 15.4° rise $59.2 \times 15.4 = 911$ B. T. U. The volume of the two tanks is 20 cubic feet, consequently the heat absorbed by the brine will be $911 \times 20 = 18,220$ B. T. U., leaving $34,400 - 18,220 = 16,180$ B. T. U., to be absorbed by brine ice. Taking the latent heat of the brine ice as 122, the amount of brine to be frozen on the coils will be $\frac{16,180}{122} = 132$ pounds. With 117 feet of submerged

1½-inch pipe, this is equivalent to a uniform coating of ice $\frac{29}{64}$ inch thick.

In raising the temperature of 1 pound of a 15 per cent solution of common salt from the freezing temperature of 12.2° to 27.6° , 13 B. T. U. are required. For the same range in temperature of 1 pound of brine ice, approximately 135 B. T. U. are required. In other words, under the above conditions there is about 10 times more refrigeration available in the 1 pound of brine ice than there is in the 1 pound of brine. Consequently, by freezing a portion of the brine on the coils the hold-over period can be greatly increased.

AIR-CIRCULATING SYSTEM.

There is a further modification of both the direct-expansion and brine-circulating systems, known as the indirect air-circulating system. This system is seldom used, except in connection with ice-cream hardening, where low temperatures must be obtained in a short time. It requires, in addition to the necessary members of the direct-expansion or brine systems, a fan, located in the cooling room over the coil bunkers and driven from without the room. The air is simply the circulating medium for producing the desired refrigeration and is forced by the fan over the cooling coils and down into the room below, where it comes in contact with and absorbs heat from the goods in storage. This results in a pure dry atmosphere, as the moisture content of the air is deposited on the surface of the coils in the form of ice and the greater portion of the microorganisms which were originally contained in the air are inclosed and rendered innocuous.

If the initial and final temperatures of the air, together with the corresponding moisture contents, are known, the refrigeration required for the simultaneous cooling and drying of the air can be ascertained. To cool the air alone necessitates the withdrawal, for every pound of air, of a number of B. T. U. equal to the product of the difference of temperature and the specific heat of air at constant pressure.

As it is common practice to measure air by volume, it is most convenient to express its specific heat in a unit of volume instead of weight. Since, however, the density of air varies with its temperature, it is impossible to obtain a value that will apply other than approximately to more than one condition. Taking, for example, air under standard conditions, density at 70° F., and a relative humidity of 70 per cent, a cubic foot weighs 0.07465 pound, and its specific heat is 0.0177.

If the initial temperature of the air in the room is 70° F. and it is cooled to, say, 20° F., the refrigeration to cool 1,000 cubic feet of air, neglecting the moisture, is $1,000 \times 0.0177 (70 - 20) = 885$ B. T. U.

Considering the moisture in the air, the moisture content at 70° F. and 70 per cent relative humidity would be 5.596 grains per cubic foot, and at 20° F. for saturation there would be 1.235 grains. Therefore, there is eliminated per cubic foot $5.596 - 1.235 = 4.361$ grains, or for the 1,000 cubic feet, $1,000 \times 4.361 = 4,361$ grains or 0.623 pound. Consequently the refrigeration required is:

	B. T. U.
Latent heat of liquefaction, 0.623×970.4	605
Cooling from 70° to 32° F., $0.623 \times (70 - 32)$	24
Freezing, 0.623×144	90
Cooling ice from 32° to 20° F., $0.623 \times 0.5(32 - 20)$	4
	723

The total heat, therefore, that must be removed in cooling the 1,000 cubic feet of air under the above conditions is $885 + 723 = 1,608$ B. T. U. In the case of cold storage the total amount of refrigeration required for air cooling depends, of course, on the number of times the air in the room is renewed in a given time. With the indirect-air system usually employed in the dairy industry the same air is kept in circulation to a great extent.

In all cold-storage work the air in the rooms must, of course, be cooled, but as the refrigeration required is generally small compared with that necessary for cooling the goods and in taking care of the heat that comes through the walls, floors, and ceiling, it is usually ignored and a liberal allowance made to cover this as well as lighting, presence of workman, poor workmanship, and other factors.

INSULATION.

The word "insulate" is derived from the Latin word "insula," meaning "island." Therefore the significance of the definition of insulate is: To place alone or in a detached situation; separated by a nonconductor from other conducting bodies; having no communication with surrounding objects. Hence insulation in a cold-storage room is applied on the interior surface of the outside walls, under the roof, and under the lowest floor, to prevent, as far as possible, the transfer of heat from exterior heat-conducting bodies like the air and the ground.

With the increased application of refrigeration the problem of properly insulating the walls, floors, and ceilings of the cold-storage rooms is of the greatest importance and should be considered in the light of a permanent investment along with the building and equipment, the returns on which should be based on the saving effected by the lower operating cost.

It is evident that after the goods in storage have once been cooled to the desired temperature, it is then merely a question of supplying

sufficient refrigeration to take care of the heat which finds its way through the insulation of the walls, floors, and ceilings of the cold-storage rooms. The greater the efficiency of the insulation the less heat will get through from without. There is a limit, however, to the amount of insulation that should be installed, which is the point where the interest on the money invested in insulation, the repairs and depreciation on same, balances the saving in operating expenses.

There is no material known that will entirely prevent the passage of heat. However, there are some which offer a very high resistance, and are therefore termed nonconductors or insulators. The best heat insulators appear to be those that contain the greatest amount of entrapped air confined in the smallest possible air space.

The function of cold-storage insulation, then, is to prevent the outside heat from passing through the walls, floors, and ceiling into the interior of the cold room. Therefore the problem is to minimize the passage of heat by interposing in the walls, floors, and ceiling a material or construction which will resist the transfer of heat from the outer to the inner side of the room. The materials most commonly used for this purpose are the different varieties of cork products, mineral wool, hair felt, rock wool, vegetable fiber, sawdust, mill shavings, etc., used in combination with wood, cement, masonry, and air spaces. At one time it was common practice in the construction of buildings for cold-storage purposes to provide a series of air spaces in the walls, some of which were as much as 12 inches wide, the supposition being that they were dead-air spaces. As a matter of fact they were not. As the air in contact with the warmer surface became heated it rose, while that in contact with the cooler surface fell, thus producing a circulation tending to equalize the temperature of the sides of the air space. Dead air, however, is a good nonconductor, but unless the air spaces are properly proportioned, the above-mentioned air currents will be set up. Therefore, it is the present practice to fill in the spaces with some porous substance to break up the space into an indefinite number of small dead-air spaces which will effectually prevent circulation of the entrapped air. On the other hand, there is danger of packing the insulating material too closely, which will result in favoring the conduction of heat through the walls.

Sawdust and mill shavings are mentioned in the above partial list of insulating materials, but they are not to be considered among the best. They can be had in any part of the country, and often without cost, and if kept dry are good insulators. It is a very difficult problem, however, to keep them dry, and when used, great care should be exercised in the construction and workmanship of the walls in order to keep out the moisture.

Planing-mill shavings are better for insulating purposes than sawdust. They are elastic, do not settle rapidly, and will not absorb moisture as readily as sawdust, and, most important, can usually be had in very dry condition. They should be odorless, free from dirt, bark, and chips, and should be well packed into place to prevent future settling. About 9 pounds per cubic foot is considered the proper density to which they should be packed.

Sawdust has in the past been used to a great extent in rural districts for insulating the walls of small cold-storage buildings, due to the fact that it is available in most country districts, and generally may be had without cost. It is not a satisfactory material, however, for insulating purposes, as it is always more or less damp. The dampness not only destroys its insulating value, but it favors the growth of molds and bacteria, first in the sawdust itself and then in the walls of the building. The rotting and the consequent heating causes the sawdust to settle and leaves open spaces, which further weaken the insulation. It also furnishes an ideal nesting place for rats and mice, and the tendency of these rodents to carry matches into their nests and to start fires is well known. When sawdust or mill shavings are to be used they should be thoroughly dried before being put into the walls. Furthermore, if air is allowed to circulate in the shavings or sawdust moisture will be deposited in warm weather, and then, again, in cold weather it will dry out. This being repeated for several years will cause the boarding and shavings to rot. If, however, the shavings or sawdust is surrounded by waterproof paper and boarded, the condensation will not occur and deterioration will be prevented.

In deciding upon an insulating material for cold-storage purposes the following points should be carefully considered: Efficiency as a heat insulator; whether or not it will retain its efficiency indefinitely; structural strength; the effect of moisture; uniformity of insulating value; whether fireproof or not; space occupied; first cost; cost of installing, etc.

The greater portion of the refrigeration required for cooling cold-storage rooms is done to remove the heat that leaks through the walls, floors, and ceilings, and only a small part is required to cool the goods in storage. As previously stated, it is necessary to pump out, so to speak, the heat that enters from the outside after the goods are once cooled to the desired temperature.

Take for example a creamery cold-storage room 10 by 10 by 10 feet, inside dimensions, which is of sufficient capacity to hold a week's output of butter from a creamery making 2,000 pounds daily. The butter will come from the churn at approximately 58° F. The average outside temperature of room is assumed to be 75° F., and the inside temperature 32° F. It is further assumed that the walls, floors, and ceiling are insulated for a heat transmission of 3 B. T. U.

in 24 hours per square foot per degree difference of outside and inside temperatures of the room. The total surface of the room is 600 square feet. Then;

	B. T. U.
The heat that will leak through into the room in 24 hours is $600 \times 3 (75-32)$..	77,400
The heat to be removed from the butter is $2,000 \times 0.5494^1 (58-32)$	28,574

Total heat that will have to be removed.....	105,974
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From the above figures it will be noted that practically three-fourths of the refrigeration required in the average cooling room is done to remove the heat that leaks in through the insulation. Hence the necessity for good insulation.

It would seem from the foregoing that the more insulation put into the walls, floor, and ceiling the better, which is true when viewed from the standpoint of the refrigerating machine, as the more and better insulation used the less work the machine will have to do. But as insulation is expensive, a point is soon reached where the interest on the money invested, repairs, and depreciation on the insulating material balances the saving in reduced machine capacity and operating expenses. By installing more and better insulation, the saving in the capacity of the refrigerating machine is an item of considerable importance and one that has not been given the attention that it justifies.

From the data at hand, it appears that the most economical point to insulate for is a transmission in 24 hours of 2 B. T. U. per square foot per degree difference of outside and inside temperature of room, when the average outside temperature is 70° F. and the inside temperature of the room is 32° F. With an average outside temperature of 70° F. and an inside temperature of 0° F., the economical point is about 1½ B.T.U. In view of the fact that dairy products are extremely perishable when held at a temperature of 60° F. or above, the added security which the lowest heat transmission affords in order to hold over temperatures in case of the machinery breaking down, or where the plant is operated during the day only, makes the increased investment in insulation desirable. Good insulation not only permits operating the plant with the least refrigeration, power, time, and cost, but also helps to reduce fluctuations in room temperature. After shutting down the refrigerating plant the inflow of heat continues, but at a constantly decreasing rate. With a properly insulated room it will be several days before the inner air temperature will be near that of the outside temperature.

As an example of the saving effected by good insulation, take two cold-storage rooms of the same size and construction, say 10 by 10 by 10 feet. The walls are assumed to be built of brick 13 inches

¹0.5494 specific heat of butter.

thick, the floors and ceiling of concrete slabs 5 inches thick, the floors resting directly on the ground in both cases. The inside temperature of the two rooms is held at 30° F. by refrigeration and the average outside temperature is assumed to be 70° F. for 90 days. Suppose one building is not insulated at all and the other is insulated for a heat transmission of 2 B. T. U. per square foot of surface per 24 hours for each degree difference between inside and outside temperature.

The heat transmission through the 13-inch insulated brick walls is taken as 11.3 B. T. U. per square foot per degree difference of inside and outside temperature in 24 hours, and that for the 5-inch concrete slabs forming the floor and ceiling 28.8 B. T. U. In view of the earth offering a certain amount of protection to the floor slabs, which were assumed to rest on the ground in both cases, only half of the temperature difference between the outside and inside air is taken in computing the heat transfer through the floor in the uninsulated room. Then, for the uninsulated room the transmission will be:

	B. T. U.
Brick walls, $400 \times 11.3 (70-30) \times 90$	16,272,000
Ceiling, $100 \times 28.8 (70-30) \times 90$	10,368,000
Floor, $100 \times 28.8 (50-30) \times 90$	5,184,000

Total heat transmitted through the walls, floor, and ceiling..... 31,824,000

This is equivalent to $\frac{31,824,000}{288,000} = 110.5$ tons.

Therefore there will be 110.5 tons refrigeration required to remove the heat which comes through the walls, floor, and ceiling, and assuming that it cost \$1 per ton to produce the refrigeration, it will amount to, in 90 days, $110.5 \times 1 = \$110.50$. Now, in the case of the insulated building we have:

	B. T. U.
Brick walls, $400 \times 2 (70-30) \times 90$	2,880,000
Ceiling, $100 \times 2 (70-30) \times 90$	720,000
Floor, $100 \times 2 (70-30) \times 90$	720,000

Total heat transmitted through the walls, ceiling, and floor..... 4,320,000

Equivalent to $\frac{4,320,000}{288,000} = 15$ tons.

At a cost of \$1 a ton for the refrigeration, it will amount to $15 \times 1 = \$15$.

Therefore, there will be a loss of $\$110.50 - \$15 = \$95.50$ on the uninsulated building in 90 days. It will cost approximately 40 cents per square foot to insulate the above-described building for a heat transmission of 2 B. T. U. per square foot per degree difference of outside and inside temperature per 24 hours, or a total of $600 \times 0.40 = \$240$. Consequently the insulation would pay for itself in about seven and a half months' operation.

As before stated, in order to obtain the maximum economy from a cold-storage plant, it is necessary that the investment and operating expenses should be so balanced that their sum is a minimum. The refrigerators or cold rooms may be constructed with a small amount or poor quality of insulation, requiring only a comparatively small investment, but on the other hand this saving must be offset by machinery of greater capacity and consequently more expensive both in initial cost and in the cost of operation. There is, however, a possibility of investing too much money in insulation, so that the fixed charges on same may be greater than the corresponding saving in investment in machinery and in operating expenses. Generally speaking, the cheaper the insulation the more should be used, and

also the more expensive the refrigeration the more insulation should be installed.

In order to determine the relative amount of refrigeration and insulation to be used to obtain the greatest saving, it is necessary to consider the cost per ton of refrigeration; the cost per square foot of insulating material; the repairs and depreciation on insulating material; the insulating value of

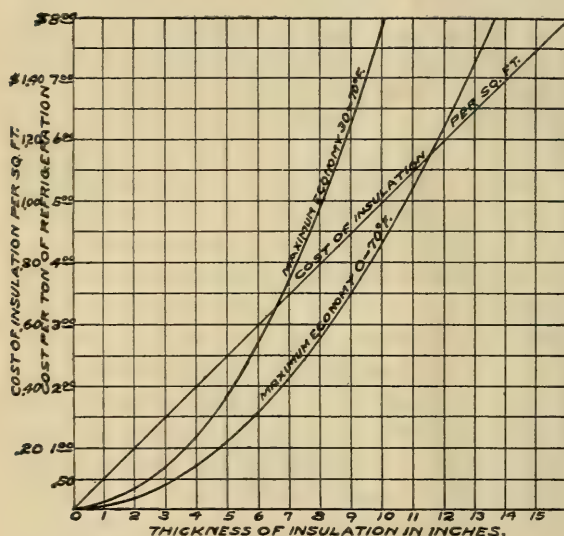


FIG. 22.—Economics of insulation.

the material; the temperature maintained inside of room; and the average outside temperature.

The curve in figure 22 is based on the above-mentioned variables, which are assumed to be as follows:

Cost per ton of refrigeration.

Cost per square foot of insulation, 1 inch thick, installed, \$0.10.

Repairs and depreciation of insulation material, 15 per cent.

Insulating value of material per board foot per 24 hours for each degree difference between the inside and outside temperature of room, 8 B. T. U.

Inside temperature of room, 30° F.

Average outside temperature of room, 70° F.

There is also shown a curve calculated from an inside room temperature of 0° and an average outside temperature of 70° F.

To use the curves in figure 22, suppose it costs \$1 per ton per 24 hours to produce the refrigeration, and it is desired to know the amount of insulation that will give the maximum economy when the inside temperature of the room is at 30°F. and the average outside temperature is 70° F. Look on the left-hand side of the figure, under "Cost per ton of refrigeration," and follow the horizontal line opposite \$1 until it crosses the curve marked "Maximum economy, 30° to 70° F.," then read at the bottom directly under the point where the curve cuts the horizontal line indicating \$1 per ton, and it will be found to require $3\frac{3}{4}$ inches of insulation. If the inside temperature of the room had been 0° and the average outside temperature 70° F., the thickness of insulation required to obtain the maximum economy would have been $4\frac{3}{4}$ inches. Then the estimate cost of insulation per square foot is found by projecting a line vertically through the intersection of the curves and the horizontal line indicating a cost of \$1 per ton of refrigeration, until it cuts the straight line marked "Cost of insulation per square foot," then reading on the left opposite this point and under "Cost of insulation per square foot," the cost per square foot of insulation is found to be $37\frac{1}{2}$ and $47\frac{1}{2}$ cents, respectively. It is assumed that the cost per square foot of insulation will be a constant in small cold-storage rooms of the size commonly used in milk plants. In the economical operation of a refrigerating plant the insulation is the most important point and great care should be exercised in its selection and installation. All exposed piping between the expansion valve and the suction side of the machine should be carefully insulated, as well as the walls of the refrigerator itself.

In the building of cold-storage rooms or boxes there is often used a construction of boards in combination with air spaces, and while cheap in first cost, in a few months in extreme cases the walls will begin to deteriorate and show increased losses. In a short time the piping in the box or room is not sufficient to hold the temperatures, and finally the capacity of the machine is not enough to do the work; whereas, with a sanitary box properly constructed of nonabsorbent material, no deterioration will occur after long and continued use. Consequently, it is very important wherever possible to eliminate wood in the construction and substitute for the walls hollow tile or brick.

When placing the insulation in the walls, floor, and ceiling of cold-storage rooms it is of the utmost importance that the workmanship be of the best. The insulation should be continuous. There should be no break in continuity where floor, walls, and ceiling meet. Each course of insulation should be well set up before the next course is put in place. In all cases the blocks of insulation should fit tightly

together. No cement should be used in the joints, but only on the back of the blocks.

The floors should be of concrete and should preferably be laid solidly on the insulating material. The insulating blocks should be laid in asphalt and coated over the top with hot asphalt and then 2 inches of concrete laid directly on the insulating material and finished with a coat of 1 inch of Portland cement.

In cold-storage rooms designed for storing milk and milk products an insulation should be used that will take a waterproof interior

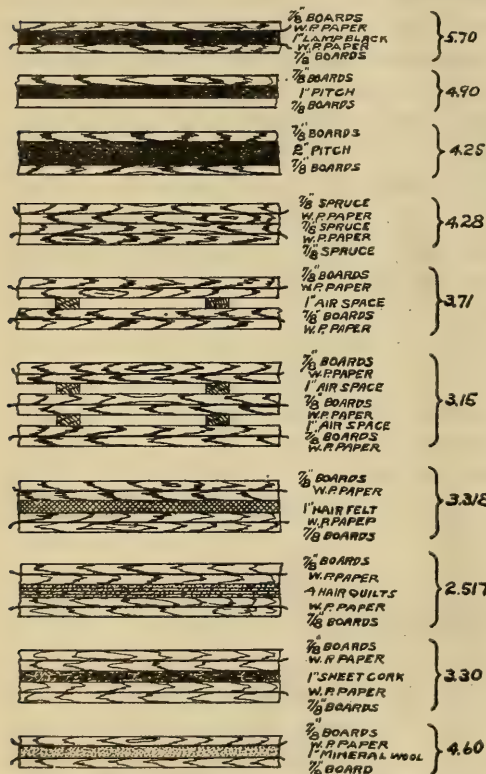


FIG. 23.—B. T. U. transmitted per square foot per 24 hours per degree difference in temperature.

finish, such as Portland or other hydraulic cement, or vitrified hollow tile laid up in cement mortar. This construction permits of being thoroughly washed out with either hot or cold water without injury to it or to the insulation proper.

Wooden floors have proved very unsatisfactory, as they rot out in a comparatively short time, due to the fact that they are more or less absorbent and can not be readily cleaned and therefore retain odors that may be injurious to delicate goods. The ability to keep storage rooms, especially where used for storing dairy products, in a sanitary condition by thoroughly washing will be appreciated by dairymen.

When brick or concrete are used in construction the

exterior of the walls should be coated with some efficient waterproofing compound; the walls should be thoroughly dried out, however, before the compound is applied. The customary method has been to waterproof the interior of the walls, allowing the outside moisture to soak through the walls until it reaches the inner film of the waterproofing compound. It is much better to waterproof the outside surface of the walls, thereby preventing the moisture from penetrating through to the inner side. In cold-storage rooms the doors perhaps afford the weakest point in the insulation. While their insulation is of

importance, their tightness and ability to be operated quickly is vastly more so. A poor-fitting door that allows the outside air to leak into the room is a source of endless expense; consequently great care should be exercised in fitting doors in place. Usually it is economy to buy a good design of commercial door, as it will fit better and not be so liable to warp as a door built by the local carpenter. With slow and heavily moving doors which bind and work badly there is a tendency on the part of the workmen to leave them open, allowing the warm outside air to rush in and replace the cold air. Equal care should be exercised in the construction of windows in the walls of cold-storage rooms. They should be constructed of three plates of glass with two half-inch air spaces. The glass plates should be carefully set in felt and made perfectly air-tight. The drawings of typical constructions of cold-storage insulations with their insulating values are shown in figs. 23, 24, 25, 26, and 27; they are taken from tests made by different authorities.

ESTIMATING THE SIZE OF REFRIGERATING PLANTS.

In determining the size of machinery for any class of work it is necessary to carefully consider the maximum or peak load that it will be called upon to carry. This often results in having to install a great deal larger machine than would be required if the load were uniform. In no class of machinery is this more apparent than in refrigerating apparatus when applied to the dairy industry.

In figure 28 (p. 61) are curves showing the relation between the milk supply and the temperature of the air. These curves are plotted from data obtained from the most important dairying States. The milk-

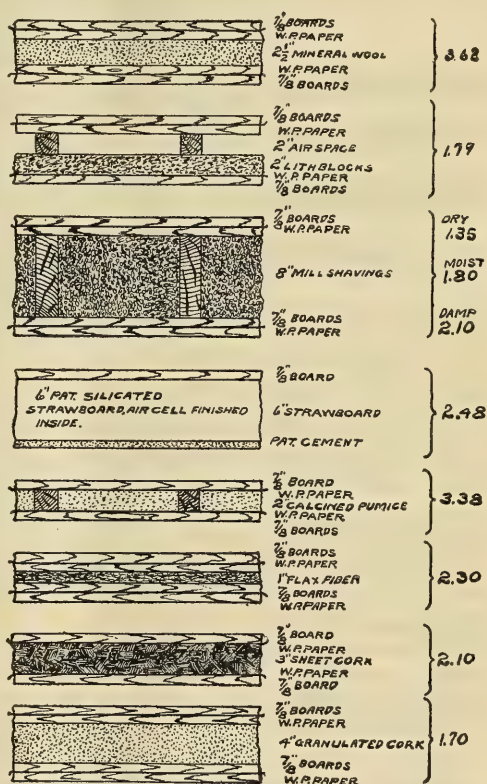


FIG. 24.—B. T. U. transmitted per square foot per 24 hours per degree difference in temperature.

supply curve is based on the monthly percentage of the average supply. The temperature curve is the average of the mean 24-hour temperatures. Referring to the curve showing the variation in the supply of milk from month to month, it will be noted that there is practically a fixed relation between the temperature of the air and the supply of milk. The average of the milk supply, which is taken as 100 per cent, is available during April and September, while the maximum occurs during June. The highest summer temperature occurs the latter part of July and the first of August, and the maximum amount of work to be done by the refrigerating plant is during

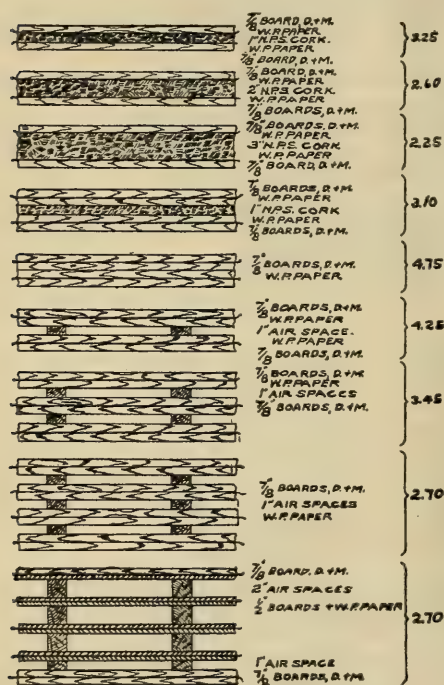


FIG. 25.—B. T. U. transmitted per square foot per 24 hours per degree difference in temperature.

July. Therefore the conditions existing at this time should be taken as a basis for determining the size of the refrigerating plant required. If the capacity of the refrigerating plant is sufficient to handle the maximum load running eight hours a day, it will handle the average load running four hours a day. The time of running the machine will decrease from a maximum of eight hours during July until it can be shut down entirely in the Northern States during December, January, and February. In the South it will be necessary to operate the refrigerating plant to some extent during the entire year. The curve marked "compressor curve" shows the approximate daily hours the compressor will have to be operated to produce sufficient refrigeration to take care of the milk during the different months of the year. This curve, however, is based on the milk supply and weather conditions existing in the Northern States, where the dairying industry is principally located at the present time. In the Southern States the daily hours of operation will have to be increased. However, the flush period is not so marked as in the North, as the seasons are longer; consequently the refrigerating load is more uniform and the peak load is not so great.

A simple and fairly accurate estimate on the size of refrigerating machine required to do the work of a given amount of ice may be made as follows:

Suppose the ice required to cool a certain size box during the hottest weather is 500 pounds per 24 hours. The refrigeration accomplished by this amount of ice melting is $500 \times 144 = 72,000$ B. T. U. Assuming that the conditions existing in the plant will justify the operation of the machine eight hours per day, then the capacity of the machine must be sufficient to extract 72,000 B. T. U. in eight hours, or in one-third of the time that it takes to melt the ice. Therefore the capacity of the refrigerating machine must be $\frac{72,000 \times 3}{288,000} = 0.75$ ton. Usually lower temperatures than can be maintained by the use of ice are desired, consequently a 1-ton machine, although slightly larger than the requirements, should be installed.

In figure 29 (p. 62) are given the maximum and average temperatures for the different States.

APPROXIMATE COST OF PRODUCING MECHANICAL REFRIGERATION IN SMALL PLANTS.

The cost of producing a ton of refrigeration mechanically depends upon so many variables, especially in small plants, that it is impossible to give more than approximate costs. The average plant used in creameries and dairies is operated about eight hours daily during the summer months when the work required of the refrigeration machinery is at its maximum. Then the total time of operation diminishes until the machine is shut down entirely or run very little during the winter months.

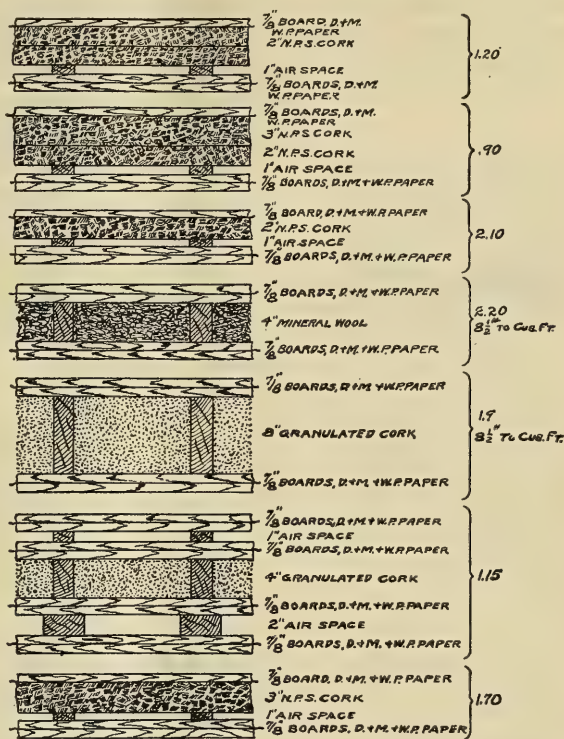


FIG. 26.—B. T. U. transmitted per square foot per 24 hours per degree difference in temperature.

In most small creameries the engine is ordinarily run for only two or three hours while the churning, working the butter, and pasteurizing is being done. The balance of the day the fire in the boiler is banked and only 10 to 15 pounds' pressure is kept on the boiler. If, in order to operate a refrigerating plant, it is necessary to keep a greater pressure on the boiler and to operate an engine which is a great deal larger than is required for the compressor, the cost per ton of refrigeration will, of course, be greatly in excess of what it would

be if the engine was of suitable size for operating the compressor only. Again, the refrigerating machines are often operated intermittently, thereby increasing the cost per ton of refrigeration above what it would be if run continuously. In view of the above, it is impractical to arrive very closely at the actual cost per ton of refrigeration when the compressor is operated by a steam engine which is also used for driving other machinery.

The curves in figure 30 (p. 63), showing the approximate cost of producing refrigeration in creameries with belted, steam-driven equipment, has been averaged from reports on a large number of creameries, and in view of the fact that the engines were used for purposes other than driving the

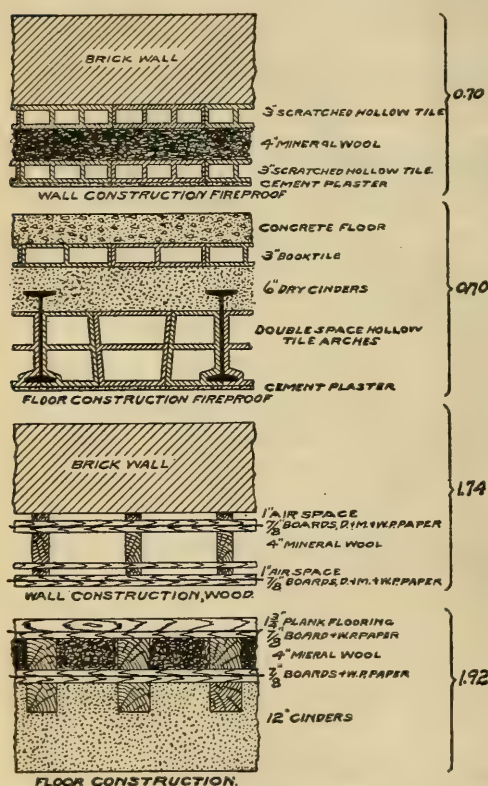


FIG. 27.—B. T. U. transmitted per square foot per 24 hours per degree difference in temperature.

refrigerating machines, it should be borne in mind that the results are only approximate and should not be considered as positive. The cooling water supplied to the condenser and the wages of an attendant have not been taken into consideration in averaging the cost of producing the refrigeration. The water in most cases costs little or nothing, and it can be used for feeding the boiler, washing utensils, and for other purposes after it has passed through the condenser, as it is only raised a few degrees in temperature. In operating small-machines of the size commonly used in milk plants,

creameries, and dairies, it is unnecessary to employ a regular attendant, as some persons regularly employed in other work on the premises can find time to start and stop the machine and to keep it oiled.

The curve marked "Total cost per ton of refrigeration" has been calculated from the estimated cost of the plant, repairs, depreciation, and miscellaneous items, such as oil, waste, packing, etc. The interest on the money invested is figured at 6 per cent and the repairs and depreciation at 10 per cent.

While the above curves representing the cost of producing refrigeration in the smaller-sized creameries are believed to represent a fair average, it is also believed that the cost can be materially lessened if more attention is paid to the economic operation of the compressor. In a great many instances the engine drove long lines of shafting that were not in the best of condition and a number of idle pulleys in addition to the refrigerating machine.

In many instances where electricity is available motors may be installed at an advantage for operating the refrigerating machine as well as other apparatus. Motors of comparatively slow-speed type can be

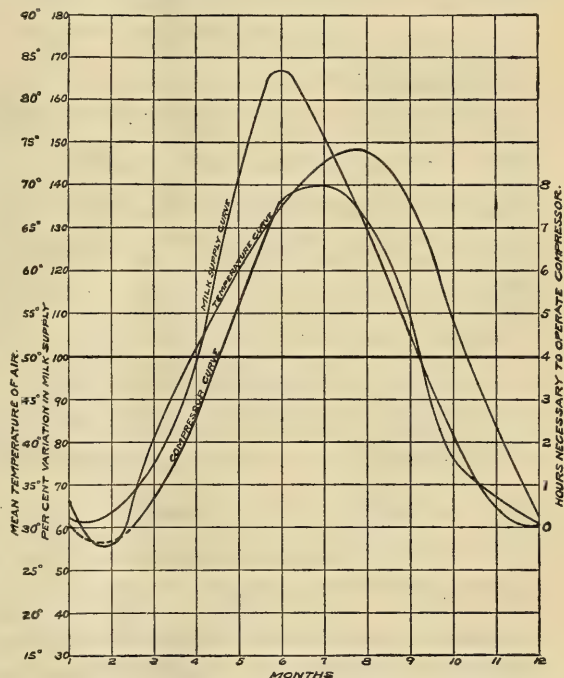


FIG. 28.—Curves showing the relation between the milk supply and the temperature of the air, averaged from the most important dairying States, and the hours necessary to operate the compressor based on the maximum amount of work being done in eight hours.

readily connected by belt to the compressor. With the present price of electric power the cost of operating small units with electricity is slightly greater than when operated by steam power, provided the steam plant is run at or about normal load. But when the engine and boiler are operated at only a fraction of their capacity they become very inefficient and the cost of power is greatly increased. In view of the fact that with electricity the consumption of power starts and stops with the opening and closing of the switch it is often more economical to install electric motors for operating small refrig-

erating machines, even though the creamery is already equipped with a steam engine. This will depend, however, on the arrangement and efficiency of the steam plant and on the cost of electric power and must be determined in each individual case by those on the premises. The cost of power per ton of refrigeration as averaged from steam-driven plants in operation will compare with electric drive at about 3 cents per kilowatt-hour.

There are other advantages in employing electric drive over steam, the value of which can not be estimated in dollars and cents, viz, cleanliness, less space required, and that the power required can be determined accurately at any time.



FIG. 29.—Maximum and average summer temperatures in different States.

Cleanliness in milk plants, creameries, and dairies is of special advantage, and with electrical drive practically all the dirt arising from smoke, coal dust, and ashes is eliminated.

It is possible to install electric motors in out-of-the-way places where engines could not be located. This feature makes it practical to locate the refrigerating machine close to the cooling rooms, thereby eliminating long leads of refrigerating piping located outside the rooms to be cooled.

The fact that the power required to operate the compressor can be determined accurately at any time is of great importance. This feature, however, may not seem of very great value at first thought, but it has been proved in many instances to produce higher economy. That the cost of production can be determined accurately is due to the fact that the cost of power is given in each monthly bill or, for that matter, can be calculated each day from the meter readings. With exact figures at his command the operator is able to detect

leaks occurring in production due either to careless operation or to deterioration of the apparatus and is able to judge of the exact value of every movement in the process.

REQUIREMENTS OF REFRIGERATING PLANTS FOR DAIRY PURPOSES.

A refrigerating plant suitable for use in milk plants, creameries, and dairies should comply with the following requirements:

- (1) It should be reasonable in cost.
- (2) Economical to operate.
- (3) Reasonably sure against breakdown.
- (4) Should produce cool and dry air in storage room.
- (5) Should produce lower temperatures than ice.

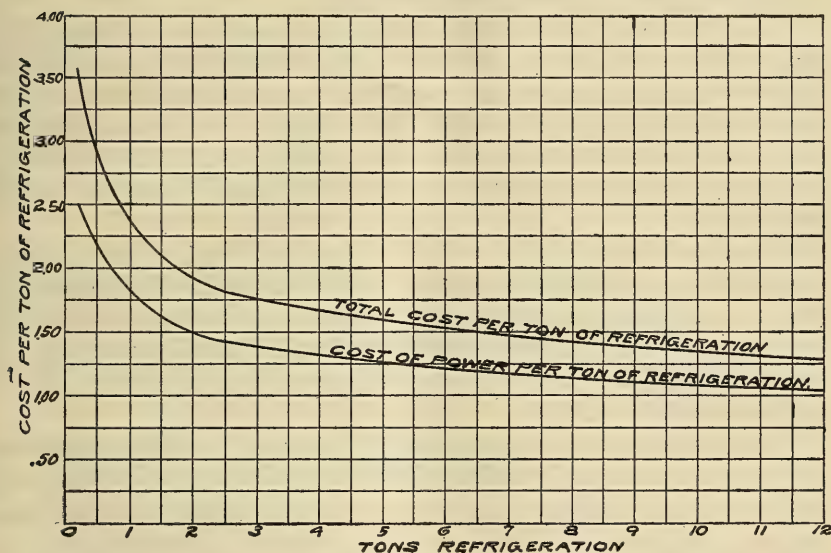


FIG. 30.—Approximate cost of producing refrigeration in the average creamery with belt-driven compressors.

- (6) Should give perfect control of temperatures.
- (7) Should be simple in construction and operation as to require little attention and be successfully operated by any careful person without any special mechanical or engineering skill.
- (8) Should occupy little space.

The initial cost of a refrigerating plant should of course be as small as possible consistent with high-grade apparatus. It is believed that no class of machinery depends more for satisfactory and economical operation on the original design, material of construction, and workmanship than refrigerating machinery. An inferior grade of refrigerating apparatus is an expensive investment at any price and should never be installed. With high-grade machin-

ery and properly arranged and proportioned accessories the cost of repairs and operation is reduced to a minimum.

In the summer months the refrigerating plant is often required to operate continuously in order to handle the increased amount of milk during the flush season, and, furthermore, there is a greater amount of refrigeration required on account of the higher summer temperature. A breakdown at this time would result in the probable loss of the stored products; besides, the daily supply of milk and cream which arrives in the plant at a temperature that will cause the rapid development of bacteria if held even for a short period. During the summer months the temperature of the condensing water will be higher, and consequently a greater quantity will be required for satisfactory operation.

With properly proportioned pipe coils, brine tanks or congealing tanks, and good air circulation within the cold-storage room, cool and dry air will be obtained and a lower temperature and purer atmosphere than is possible with ice. The temperature obtained in the average refrigerator cooled with ice is seldom below 45° or 40° F., and the air always contains more moisture than it should for the best results.

When employing a properly designed mechanical refrigerating plant the temperatures are under perfect control of the operator, regardless of weather conditions; consequently the result is a higher grade and more uniform product. It is absolutely necessary in manufacturing the highest grade dairy products to be able to control the temperatures at will.

As the refrigerating plant is generally operated by persons unskilled in the management of machinery of this type, it should be as simple as possible in its construction and operation, especially in the smaller plants. In the larger plants, however, where an experienced attendant is employed, the equipment may be more elaborate. The apparatus should be designed to occupy as small a space as possible consistent with strength and efficiency, and as it is to be operated by unskilled persons, nothing but the very best material and workmanship should be used in its construction.

In order to keep the size of the refrigerating plant as small as possible, it is advisable to provide storage tanks of ample capacity. The brine should be cooled and a large quantity held for quick action when needed, as when a supply of warm milk is received into the plant and it is necessary that it should be cooled in the shortest possible time. And, further, the cold brine in the storage room can be depended upon to hold the temperatures in case of a temporary shutdown of the refrigerating machine.

In view of the fact that the quantity of milk or cream is liable to vary greatly from day to day, depending upon the supply from the

farms and upon the amount sold, it is necessary to have a considerable margin of safety in the capacity of the brine-storage tank.

The application of refrigeration for dairy purposes depends upon so many variables that it is practically impossible to treat the subject other than in a very general way. Each particular case demands special study in order to obtain the best results, as there are many methods of application according to the character of the business and its particular phases. Generally speaking, however, the brine-storage or congealing-tank system seems to be the one best adapted for most plants, but the medium surrounding the evaporating coils may be either a brine solution of sufficient strength not to freeze at the ordinary working temperature, or it may be confined air, or it may be milk brought in direct contact with the cooling surface of pipes in which the refrigerant is evaporated. In many instances it may be advisable to employ a combination of the different methods in order to obtain the most satisfactory and efficient arrangement.

As there are many methods of application of refrigeration to milk and milk products, we will endeavor to differentiate as far as practicable between the various applications and discuss in a general way what seems to be the one best suited for the purpose, and for this reason the following classifications are made:

- (1) Cooling milk on the farm.
- (2) Maintaining temperatures during transportation.
- (3) Receiving stations.
- (4) Cooling milk in bottling plants: (a) pasteurizing plants; (b) raw-milk plants.
- (5) Refrigeration in creameries, general.
- (6) Local creameries.
- (7) Centralized creameries.
- (8) Auxiliary creameries.
- (9) Cream-buying stations.
- (10) Market cream plants.

COOLING MILK ON THE FARM.

As the influence of both time and temperature combine to hasten the development of bacteria in milk, it is obvious that it should be cooled just as soon as possible after being drawn from the cow. As has been previously pointed out, the cooling of fresh milk retards the development of the bacteria, which produces fermentation in milk, thereby in turn destroying the milk by causing it to sour. The indications are that at 32° F. the development of bacteria is not only retarded, but there is apparently an actual decrease in their number when held at this temperature. The bacteria referred to, however, are those found in milk, even though produced under favor-

able hygienic conditions, and not to pathogenic (that is, disease-producing) bacteria. It is impracticable to reduce the temperature of milk much below 50° F. in summer without employing a refrigerating machine or ice, and as the former is too expensive for the ordinary farmer, we are limited to the use of ice or well water. Where ice is plentiful and may be had at a nominal cost it is an easy matter to reduce the temperature to, say, 40° F., and by referring to Tables IV, V, and VI under "Influence of temperature and time on the development of bacteria in milk" it will be noted that the multiplication of bacteria at this temperature is very small.

In those locations where natural ice is available it is comparatively an easy matter to cool milk or cream on the farm before carrying it to the receiving station or creamery. This may be done by running the milk or cream over some form of cooler in which cracked ice or a mixture of ice and salt is placed, or through which cold water is circulated.

Where the milk or cream is placed in cans and set in cool water, or even in a tank filled with ice and water, the cooling goes on very slowly, especially if the cans are large. The outside portion, however, may be cooled in a comparatively short time, but unless it is stirred repeatedly it will take considerable time before the interior is cooled down to a point where the development of bacteria is retarded to such an extent that the milk or cream may be safely carried to the receiving station or creamery, as the case may be. It is often the case that a can of milk is set into a cooling vat in which the cooling medium is lower in level than the milk in the can, in which case the milk in the lower part of the can may be cooled down to approximately the temperature of the cooling medium, while that above the level will remain at the higher temperature of the atmosphere; consequently, when the milk is stirred the whole will turn sour and spoil. The cold milk, being heavier than the warm, will naturally remain at the bottom of the can, while the warmer and therefore lighter portion will remain at the top, and practically no circulation will take place and the transfer of heat by conduction in this case is very slow.

If proper care is exercised, however, milk and cream may be cooled down to a temperature sufficiently low to get to the receiving station or central creamery in good condition by running spring or well water through the cooler. In the winter months the lower atmospheric temperatures assist in the cooling, but in the hot summer months the higher temperatures of the atmosphere retard the cooling; consequently, during the hot weather the milk or cream should be run over the cooler very slowly, and if its temperature is not sufficiently lowered it should be run over the second time. In this

way it is possible to get the temperature down to within 2° or 4° of the cooling medium.

As the development of bacteria begins as soon as the milk is drawn from the cow, it is of the utmost importance that the cooling be done as quickly as possible after milking, in order to keep the initial number of organisms down to a minimum. The rapidity at which the development of bacteria goes on in milk at a given temperature depends, of course, on the initial count, hence the importance of keeping the initial count as low as possible.

Tests were made to determine the time required to cool milk by placing a 10-gallon can in a box and running cooling water around the can, as shown in figure 31 (p. 68). The average temperature of the water was 62.6° F. and the flow of water was regulated so that there was practically no difference between the inlet and outlet water. Thermometers were placed in the can, as shown in the attached sketch, and readings were taken every 15 minutes until the temperature of the milk was approximately that of the cooling water. The results of these readings are plotted in the form of curves, which are numbered from 1 to 7, inclusive. Curve No. 8 is plotted from thermometer readings taken in the milk at top of can and shows that that part of the milk above the water level remains from 5° to 6° warmer than the portion below the water level; consequently, bacteria will develop at a higher rate in that portion of the milk above the water level and when mixed will hasten the souring of the milk, both by raising the temperature of the whole and by the increased number of bacteria contained in the warmer portion.

The curve showing the comparatively rapid decrease in temperature when the milk was thoroughly stirred at intervals of 15 minutes demonstrates the advantage of agitating the milk while cooling.

The time taken to cool the milk in either case, however, is too great for good results, and the tests serve best to demonstrate the necessity of employing some efficient form of milk cooler suitable for farm use.

Figure 32 (p. 69) shows the method of cooling milk employed on the United States experimental dairy farm located at Beltsville, Md. The equipment consists of a one-fifth ton refrigerating machine operated by a one-half horsepower motor, a small rotary circulating pump driven from the shaft of the refrigerating machine, and a corrugated milk cooler. Water, instead of brine, is used for circulating through the cooler as the night's milk is cooled, placed in cans, and set into the tank until the next morning; if brine were used it would corrode the cans. The tank holds about 120 gallons of water, which is cooled down to approximately 35° F. and held at this temperature until time for cooling the milk, when it is pumped through

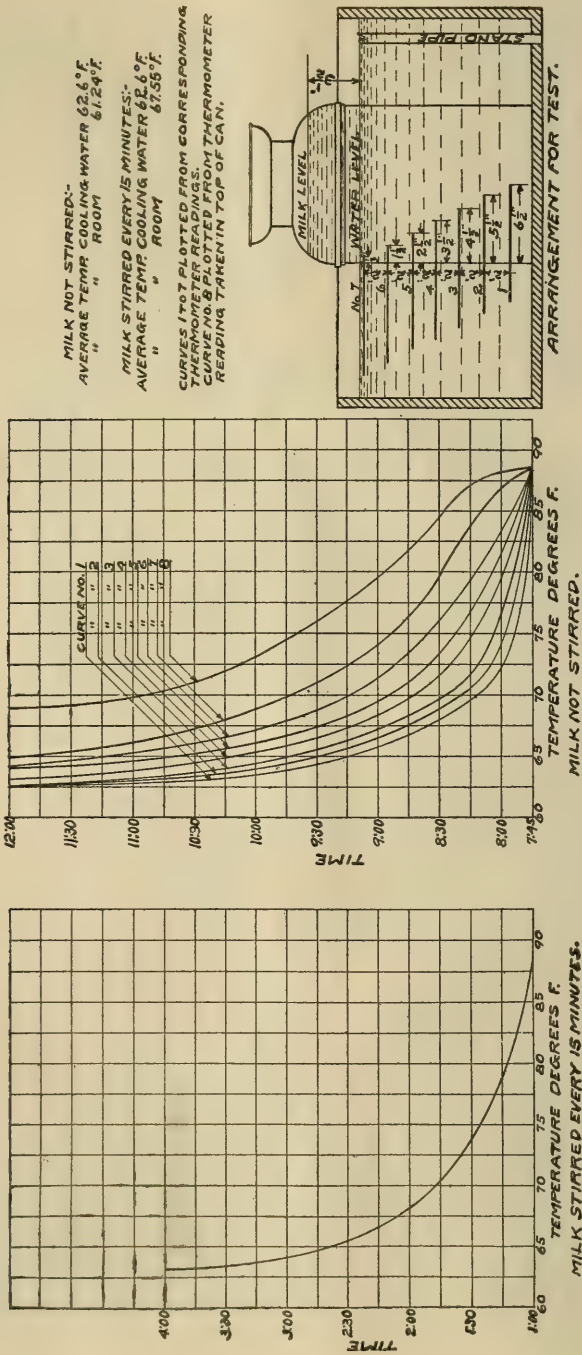


FIG. 31.—Cooling milk with running water.

the cooler by the small rotary pump. The water is allowed to pour back into the tank, consequently the temperature of the volume of water gradually rises. During the warmest weather it was necessary to run the refrigerating machine from 8 to 10 hours a day in order to cool the water down to 35° F. and hold it at this temperature until used. The volume of milk handled was that from 15 cows and it was cooled entirely by the refrigerating water from a temperature of about 98° to 35° F. Had well water been used in one section of the cooler at least half of the refrigerating duty would have been taken off the machine and the time of operating the machine would have been reduced one half, or, for the same number of hours of operation the

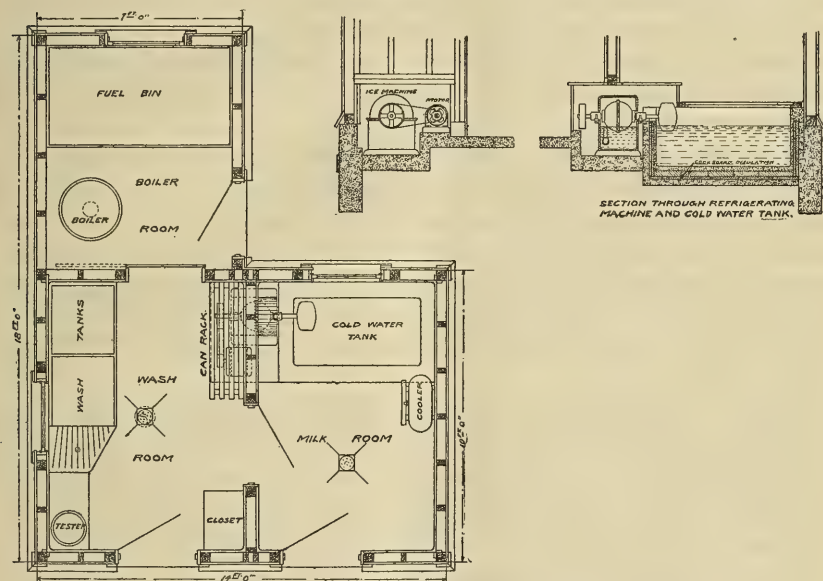


FIG. 32.—20-cow farm milk house equipped with refrigerating machine.

machine would have taken care of the milk of double the number of cows.

The cost of electric current at the experimental farm is 6 cents per kilowatt-hour, and as the input to the motor is about 0.55 horsepower, the cost of power for operating the machine is $2\frac{1}{2}$ cents per hour, or 20 cents for an 8-hour day. The amount of cooling water required is about 25 gallons an hour.

MAINTAINING LOW TEMPERATURES DURING TRANSPORTATION.

A great deal of the milk consumed in the cities at the present time is transported in wagons, or in the ordinary baggage car in use on the steam railroads or on the interurban electric railways, with no provision for holding the milk at low temperatures.

If, however, milk is thoroughly cooled on the farm and placed in large cans properly jacketed it will arrive at the city plant in good condition under ordinary weather conditions providing the time required for transportation is not over four hours. The transfer of heat through milk is principally by convection, and when in large volumes the transfer is very slow unless the milk is agitated.

The time taken in the transportation of milk from one point to another, together with the facilities available for holding it at low temperatures, determine, to a great extent, the initial temperature to which it should be cooled. For short distances, or short preservation of a few hours only, it is believed that a temperature of less than 50° F. should be maintained. Some lactic acid bacteria will multiply even at this temperature and will cause a souring of the milk, but the increase is slow and for a few hours no serious results will occur. At temperatures below 50° F., however, the rate of bacterial growth is materially decreased.

If, on the other hand, milk is to be shipped long distances, the initial temperature must be lower, assuming that no provision is made for maintaining temperatures during transportation. For comparatively long-distance shipments, where the milk is in transit for several hours, it is necessary to cool it down near the freezing point. The point to which milk should be cooled, therefore, depends on the time taken in transportation and must be determined for each particular case.

In order to maintain a low temperature as long as possible, the cans should be well jacketed. The curves in figure 33 (p. 71) show the result of jacketing the cans. The cans were set in an open truck with no covering to shield them from the direct rays of the sun. Long-stemmed thermometers were inserted through holes drilled in the covers of the cans. Thermometer readings were taken every 15 minutes and the results plotted in the form of curves. The milk was hauled a distance of 13 miles through the country and the average air temperature during the trip was 82.65°. It will be noted by referring to the curves that the total rise in temperature of the milk contained in the hair-quilt-jacketed can was 5½°, while that in the can wrapped in wet burlap was about 8½°, and the unjacketed can showed a rise in temperature of 28½°. It is obvious from the curves that it pays to jacket the cans in order to maintain a low temperature during transportation.

There are at the present time two types of refrigerator cars designed especially for the transportation of milk. One is an ordinarily constructed car of the baggage type, in which the milk cans are set and crushed ice packed around them. These cars are only good for comparatively short hauls, as they are poorly insulated or in most cases not insulated at all. The water from the melted ice

is allowed to run out at the doors, or through cracks in the floors. The other type of car is provided with ice bunkers or brine tanks. In these cars the bunkers are located in the ends of the car and have a ratio of ice to loading capacity of about 1 to 11 cubic feet. In some of the more recent designs of milk cars a mixture of salt and

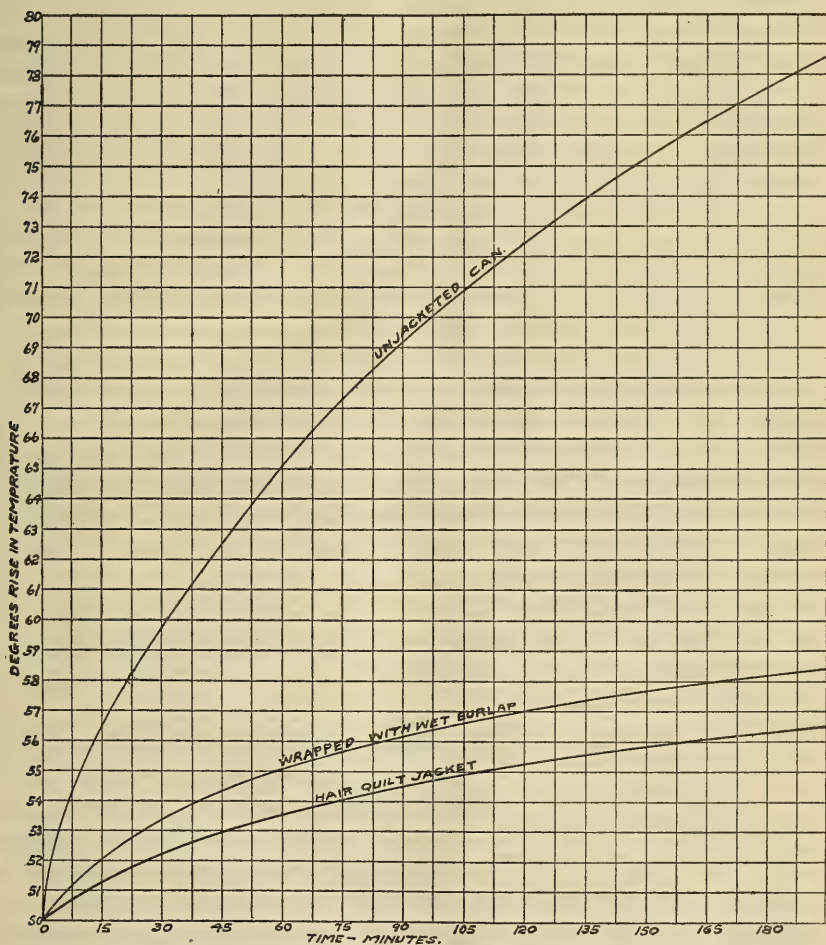


FIG. 33.—Curves showing the relative rise in temperature of milk contained in insulated and uninsulated cans. Average air temperature, 82.65° F.

ice is used to obtain lower temperatures than can be had with ice alone.

One of the latest designs of refrigerator cars for use in transporting milk, employing a mixture of brine and ice, is constructed with two refrigerator compartments, each having a floor capacity of 160 46-quart cans, 13 inches in diameter. The volume of the refrigerating compartment is 1,468 cubic feet. The design of brine

tanks consists of two tanks having a radiating surface of 226 square feet and a volume of 77.25 cubic feet. The screened portion above the tanks has a volume of 9.42 cubic feet, making a total capacity of 86.67 cubic feet, or a total of 3,814 pounds crushed ice, weighing 44 pounds per cubic foot. The ratio of tank radiating surface to loading volume is 1 square foot to 7.48 cubic feet, and the ratio of ice to milk is 2 pounds of ice to 1 gallon of milk. The tanks have a 2-inch free-air space around them and are 15 inches above the floor. They are separated from the storage rooms by a partition open at top and bottom and screened, thus creating a circulation. Any moisture from tanks is carried off from drip pan through drain pipes and traps. The tanks are connected by 1½-inch pipe, creating to some extent a circulation. This pipe also regulates the brine to a uniform height in both tanks, the height of the pipe above the bottom of the tank being so arranged that a certain amount of brine remains. A riser connection to the pipe forms an overflow.

When refilling the tanks, the valve in the pipe connecting the tanks is opened and all water or brine above the horizontal pipe is drained off. Before refilling the tanks with crushed ice and salt the valve is again closed, causing the warm water to rise to a height equal to the top of the pipe. Any surplus water runs off through overflow pipe and outside trap without egress of air. The valve is manipulated by a rod and universal joints from the roof of the car by removing the plug door.

When it is necessary to clean the tanks, the round plugs at the bottom are unscrewed about one-fourth inch, when they will release the brine, and after it has drained off the plug can be entirely unscrewed and the settlings removed.

In order that the car can be kept in a sanitary condition the floor is covered with galvanized sheet iron, all crevices being soldered, and after each trip or shipment of milk the floors are scrubbed.

It is practicable with this type of car to maintain a temperature of about 35° or 40° F. The milk must be precooled, however, to about this temperature before it is placed in the car, as the refrigerating apparatus is not intended to receive warm milk from the shipper and reduce its temperature to any great extent during transit. A longitudinal section of this car is shown in figure 34 (p. 73).

COOLING MILK AT RECEIVING STATIONS.

Receiving stations as applied to the milk industry are established for the purpose of receiving, cooling, and handling milk preparatory to shipping. They are located at suitable points along the railroads in dairy sections. The milk is brought to the receiving station by the farmers, usually twice a day during the summer months, early in the

morning and again in the evening. During the winter months the farmers often hold over the evening's milk until the following morning, making only one delivery a day. This is especially true when the farm is located at some distance from the receiving station. During warm weather, however, one delivery a day is impracticable, unless some method is provided on the farm for holding the milk at a temperature sufficiently low to prevent the rapid development of bacteria.

It is necessary that the receiving stations be provided with some means of cold storage in which to store overnight the milk which is received in the evening, and to guard against delays in railroad service, etc.

Most of the receiving stations are owned and operated by the city milk dealers. A few, however, are cooperative or have independent owners. The equipment of these stations varies greatly. The equipment of the smaller stations usually consists of a water tank for ice water and cans, with a small boiler to produce hot water or steam for washing cans and other utensils. The more elaborate establishments are equipped with pasteurizers, bottling machinery, bottle washer, separator, churn, cream vats, and an ice crusher or a refrigerating machine. The latter type of stations are equipped with the view of regulating as far as possible the surplus milk received during the flush season at the station instead of in the city by making butter, condensing, or by separating and shipping only the cream.

As soon as the milk is received it is immediately sampled, weighed, and cooled and either bottled or placed in cans ready for placing on board the cars. In the smaller stations the cooling is accomplished by setting the cans into a tank containing ice water, but in the more elaborate establishments

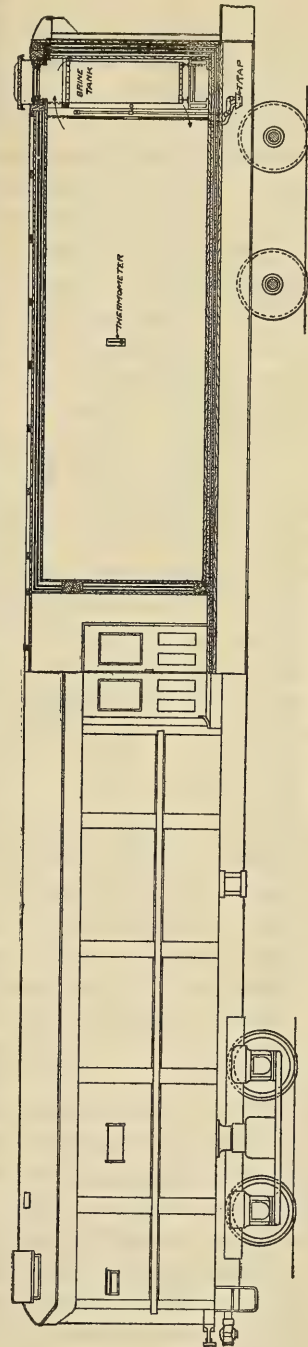


FIG. 34.—Modern refrigerator car.

as soon as the milk is received it is weighed and dumped into a vat from which it runs over the cooler to the bottling machine or into cans. Ice water or brine, or often a combination of the two, is circulated through the pipes of the cooler; ice water being run through the upper tubes and brine through the lower. The principal work, therefore, of the receiving station is that of cooling and preparing the milk for shipment. The lower the temperature of the milk, so long as it is kept above the freezing point, the better. With the present state of development of refrigerator cars used in the transportation of milk, they can not be depended upon for lowering the temperature to any great extent during transit; consequently the milk should be thoroughly cooled before loading on the cars. Usually several hours elapse between the time the milk is drawn from the cow until it is loaded on board the cars, which makes it imperative that it be precooled.

The cooling takes place early in the morning and late in the afternoon, as the milk is received. The time required for cooling seldom exceeds two hours for each period, making the total time employed in cooling about four hours daily. Owing to the short time in which the cooling is done the capacity of the refrigerating apparatus is necessarily large for the amount of work required. It is possible, however, to decrease the capacity of the plant by running the machine a longer time and storing refrigeration in brine, which can be held for quick action when needed.

COOLING MILK IN BOTTLING PLANTS.

Milk-bottling plants are usually located in cities or towns. The milk is generally shipped in cans direct from the farms or receiving stations, arriving at the bottling plants at a temperature of approximately 60° F. As soon as the milk is received at the city plant it is cooled to a temperature of 45° or 50° F., bottled, and placed in a refrigerated room, and held until the following morning, when it is delivered to the consumer. As the temperature of the room is around 32° F., the milk will come out in the morning at 35° or 40° F.

PASTEURIZING PLANTS.

In those plants where the milk is pasteurized previous to cooling the refrigeration required is, of course, considerably greater than in raw-milk plants, where the temperature of the incoming milk is simply reduced to 35° or 40° F. The amount of refrigeration required, however, depends upon the pasteurizing equipment employed.

There are in use at the present time two systems of pasteurization, known as the "holder" and "flash" processes.

The holder process consists in holding the milk or cream for about 30 minutes after it has been heated to the pasteurizing temperature of 140° to 150° F., either in the same apparatus in which the pasteur-

ization takes place or in separate holding tanks arranged for the purpose, after which it flows to the coolers.

In the "flash," or continuous, process the milk flows from the receiving tank to the pasteurizer, where it is heated to a temperature of from 160° to 165° F. in from 30 seconds to a minute, and from thence to the coolers, where it is cooled.

It is obvious, therefore, that there is more refrigeration required for a given amount of milk or cream in the latter, or "flash," than in the former, or "holder," process. It is advisable, however, in both the "flash" and "holder" processes of pasteurization to install between the heater and the cooler a regenerator or heat exchanger, in which the heat is transferred from the hot milk leaving the heater to the cold incoming milk; consequently the milk entering the heater is thus heated while that entering the cooler is partly cooled, the cooler proper reducing the temperature to the point desired.

The milk coming from the regenerator enters the cooler at an average temperature of about 88° F. and is reduced by the water section of the cooler to about 75° F. It then enters the brine section of the cooler, where the temperature of the milk is lowered to an average of 45° F. by low-temperature brine circulated through the coils of the cooler, or in some cases by direct expansion of the refrigerant in the coils. The cooled milk then flows from the cooler to the bottler, where it is bottled and capped, after which it is stored in a refrigerated room and allowed to remain overnight. As the temperature of the storage room is around 32° F. the milk is further reduced to approximately 35° F., at which it goes on the wagons the following morning and is delivered to the consumer.

The work required of the refrigerating machine in a plant of this kind is that necessary to reduce the temperature of the milk from about 75° F., the temperature at which it leaves the water section of the cooler, to, say, 45° F., the temperature at which it leaves the brine section of the cooler, and that necessary for further cooling the milk after it is placed in the cold storage room; also that required to take care of the heat that comes through the insulated walls of the storage room and in lowering the temperature of the glassware and bottle cases. The heat that will come through the walls of the room, of course, depends upon the size of the room, the quantity and quality of the insulation used, and upon the temperature of the outside air.

Assuming a plant handling 1,000 gallons of milk daily, the size of the storage room necessary will be approximately 12 by 13 by 12 feet, with an anteroom, say 6 by 12 feet, giving a total square foot surface of 1,316. If the walls, floor, and ceiling are insulated for a heat transmission of 2 B. T. U. per square foot per 24 hours, for each degree difference between the inside and outside temperatures, and if the average outside temperature is 80° F., then the

refrigeration necessary in 24 hours, when the plant is operated under the foregoing conditions, is:

	B. T. U.
Removing heat coming through walls, floor, and ceiling, $1,316 \times 2 (80-32) =$	126,336
Cooling 1,000 gallons of milk, $1,000 \times 8.6 + .95 (75-32) =$	351,310
	477,646

Additional refrigeration is also required for cooling the glassware and boxes, also a considerable amount is lost due to opening doors and the presence of lights and workmen inside the room. As it is impossible to calculate the refrigeration lost in opening doors, it is customary in practice to allow about 50 per cent additional to cover this. Therefore, the total refrigeration required in 24 hours is, $477,646 \times 1.50 = 716,469$ B. T. U. or $\frac{716,469}{288,000} = 2\frac{1}{2}$ tons. But as the refrigerating machine in a plant of this size is operated only about 8 hours during the 24, the capacity of the machine will have to be three times as large, or $7\frac{1}{2}$ tons.

The operation of pasteurizing, cooling the milk to approximately 45° F., and bottling and storing takes about two hours; consequently it is necessary to have a large volume of cold brine available for this work. The cooling of the brine is accomplished during the forenoon, before the milk arrives, and as the temperature of the brine rises during the cooling process, it is again cooled down in the afternoon and depended upon to hold over temperatures in the storage room during the night.

As a cubic foot of calcium-chlorid brine will absorb about 52 B. T. U. for each degree rise in temperature, and allowing a 15 degree rise, 30 to 45 degrees, each cubic foot will take up $52 (30-45) = 780$ B. T. U.

The volume of brine necessary for cooling the milk will be $\frac{351,310}{780} = 450$ cubic feet, providing the refrigerating machine is not operated at the time, but as a $7\frac{1}{2}$ -ton machine is capable of extracting $12,000 \times 7.5 = 90,000$ B. T. U. an hour, or during the two hours taken to cool the milk the machine will extract $90,000 \times 2 = 180,000$ B. T. U., consequently the actual cubic feet of brine required is $\frac{351,310 - 180,000}{780} = 219.6$.

Another method of calculating the amount of brine storage required to cool a given amount of milk, based on the capacity of the compressor used for cooling milk, is as follows:

$$T = \frac{(WRm) - (12,000 CHm)}{60 Rb}$$

Where T = cubic feet of brine in tank.

W = weighing of milk in pounds.

Rm = temperature range of milk.

C = capacity of compressor used for cooling milk.

Hm = hours required for cooling milk.

Rb = temperature range of brine.

Taking the values in the case under consideration and substituting in the above formula and solving for the number of cubic feet of brine, we have:

$$T = \frac{(8,600 \times 43) - (12,000 \times 7.5 \times 2)}{60 \times 15} = 211 \text{ cubic feet}$$

During the 16-hour shutdown period the heat that will come through the walls, floor, and ceiling will be $\frac{126,336 \times 16}{24} = 84,224$

B. T. U., then 219.6 cubic feet of brine will absorb in rising 1 degree $219.6 \times 52 = 11,419$ B. T. U., or the temperature of the brine will rise during the 16-hour shutdown period, disregarding the milk in storage, $\frac{84,224}{11,419} = 7.4$ degrees.

A cubic foot of milk in rising 1 degree will absorb about 61 B. T. U. Therefore the milk in storage, disregarding the brine, would rise only $\frac{84,224}{8,052} = 10.5$ degrees.

Considering both the brine and milk, a cubic foot will absorb $\frac{132 \times 61 + 219.6 \times 52}{132 + 219.6} = 55.4$ B. T. U., and the rise in temperature will be $\frac{84,224}{351.6 \times 55.4} = 4.3$ degrees during the 16-hour shutdown period.

Had the refrigerating machine been of sufficient capacity to have cooled the milk through the required range of temperature in the two hours it took to pasteurize, the size of the machine necessary would have been $\frac{351,310 \times 24}{2 \times 288,000} = 14.6$ tons. A machine of this size would, therefore, be idle most of the time, and as the initial cost of the larger machine and equipment would be a great deal more than the smaller one, it would be poor economy to install the larger machine.

When either the "flash" or "holder" process of pasteurization is employed, the temperature of the milk is generally first lowered to approximately 75° F. by water from the city mains or from wells; consequently the refrigerating machine has only to lower the temperature of the milk from the temperature at which it leaves the water section of the cooler to the temperature attained in the storage room.

RAW-MILK PLANTS.

In raw-milk plants it is only necessary to cool the milk from the temperature at which it is received, say 60° F., to a final temperature of approximately 32° F. It is usually pumped directly from the

receiving tank through some form of cooler to the bottler, where it arrives at about 45° F., after which it goes to the storage room. The refrigeration in the storage room is obviously the same as in the pasteurizing plants.

The refrigeration necessary to reduce the temperature of the milk from 60° to 32° F. is $1,000 \times 8.6 \times 0.95 (60 - 32) = 228,760$ B. T. U. The heat coming through the floors, walls, and ceiling is the same as before. Therefore the total amount of refrigeration required in 24 hours, allowing 50 per cent for opening doors, presence of workman, poor workmanship, etc., is $\frac{532,644}{288,000} = 1.85$ tons, or to do the work in eight hours the size of the machine required is $1.85 \times 3 = 5.55$ tons.

The volume of brine required to cool the 1,000 gallons of milk with machine running is $\frac{228,760 - 133,200}{780} = 122.5$ cubic feet. The heat

that will come through the walls, floor, and ceiling is $\frac{126,336 \times 16}{24} = 84,224$ B. T. U. The rise in temperature of brine and milk will be $\frac{84,224}{254.5 \times 56.7} = 5.8^\circ$.

In figure 35 (p. 79) are shown curves of the approximate size and cost of belt-driven refrigerating equipment for various sized milk plants.

REFRIGERATION IN CREAMERIES.

GENERAL.

In the application of mechanical refrigeration to creameries the first method employed for cooling cream was to allow it to run over a cream cooler on the way from the separator to the cream vat. This method allowed the cream to be exposed to the air and its contaminating influences; besides, there was no way provided for holding the cream at a constant temperature after it had reached the vat.

The next step was to place the brine piping in an open cream vat. This caused unequal temperatures in the cream and prevented the ripening process from going on at a uniform rate, as that portion of the cream in close proximity to the cooling pipes was chilled down considerably below that at some distance from the pipes. The cream was still exposed to the atmosphere, however. Consequently this method was finally discarded.

Then followed the method of locating the brine or ammonia piping in the water space surrounding the vat, but with this arrangement, as in the foregoing, it was necessary to stir the cream occasionally in order to equalize the temperature of the mass. This method was an improvement, however, as the piping submerged in the jacket water became coated with ice and after the circulation of brine or ammonia had been discontinued the ice would melt and maintain a

fairly low temperature until the cream was ready to churn. This method also had the additional advantage of allowing the brine to be circulated through the coils in the lining of the cream vat after the plant proper had been shut down.

The latest ripening apparatus is arranged for brine circulation through a spiral immersed in the cream and which is rotated at a constant speed, thereby maintaining a constant temperature. By varying the flow of brine any desired temperature may be obtained. The vats are closed and insulated. Consequently contamination

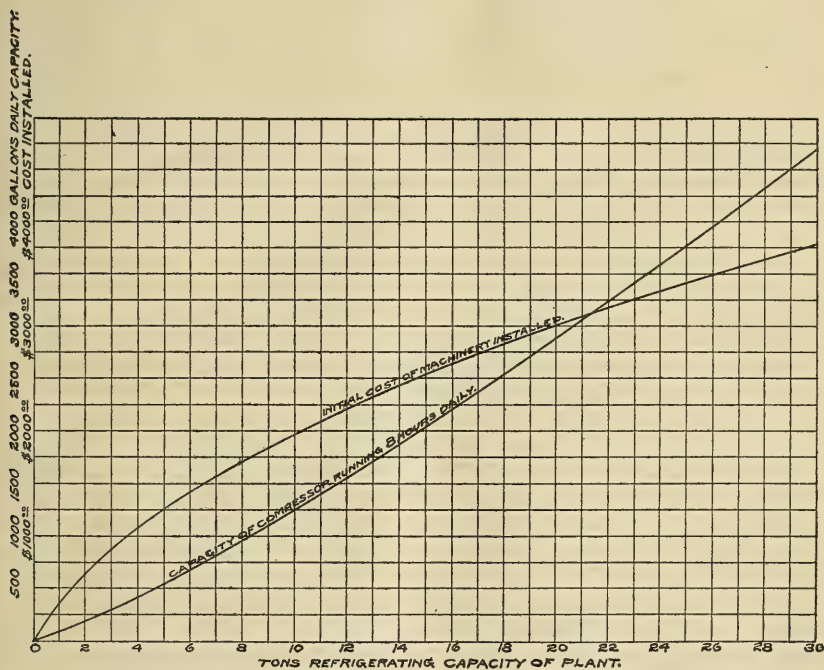


FIG. 35.—Curves showing the approximate size and cost of belt-driven refrigerating equipment for various size milk plants.

from the surrounding atmosphere and change in the temperature of the cream are prevented.

In no business is temperature control of more importance than in the handling of milk and its products. The perishable nature of milk and the rapidity with which it deteriorates when exposed to ordinary temperatures make thorough cooling facilities a necessity.

In the production of the highest grade of butter it is absolutely necessary that the temperature of the cream during the ripening process be under perfect control in order to check any further fermentation when the proper degree of acidity is reached. As the control of temperatures is very important in the manufacture of high-grade butter, it can best be accomplished by means of mechanical refrigeration, as it enables the buttermaker to control the tempera-

tures of the cream at will, and furthermore mechanical refrigeration does away almost entirely with the mold and slop that must necessarily follow the use of ice. A creamery equipped with a mechanical refrigerating plant can at all times, provided the cream is of good quality, turn out a uniform grade of butter, regardless of weather and temperature changes.

In the modern creamery refrigeration is employed in connection with the processes of pasteurizing, ripening; churning, in the preparation of starters, cooling water for washing butter, in cooling storage for the finished products, and frequently the raw products.

In the pasteurization of cream the same methods are employed as in the pasteurization of milk, viz, the "flash" and "holder" processes. In the "flash" or continuous process of pasteurization the cream is heated to a temperature of 160° F. in about 30 seconds and is then run over some form of cooler where the temperature is lowered to about 65°. From the cooler it is run into the ripening vats, where the proper temperature is maintained for 18 to 20 hours, at which time the cream has ripened sufficiently for churning. As a temperature of 65° is entirely too high for churning, it is lowered by running cold water or brine through the coils in the vat or through the coils of the cooler, should a cooler be used, and the temperature lowered to that necessary for churning.

In practice, however, the ripening temperature of cream varies within wide limits. A ripening temperature that will give good results under certain given conditions would, perhaps, give poor results under different conditions. Consequently the existing conditions will to a great extent govern the ripening temperatures. When the cream is ripened, cooled, and churned on the same day, a higher ripening temperature is of course necessary, while, on the other hand, if the cream is ripened overnight, a comparatively low temperature is employed. The range of ripening temperatures varies from 60° to 80°, but it is believed that between 60° and 70°, with an average of 65°, the best results are obtained, as cream held at these temperatures does not ripen very rapidly. Consequently the desired degree of ripening is approached very slowly and the fermentation may be checked quickly when the desired degree of acidity is reached, thereby reducing to a minimum the chances of getting overripe cream. If, however, the cream is ripened at a high temperature there is a great danger of getting overripe cream.

During the ripening process extreme and rapid changes of temperature in the cream should be avoided as much as possible, as the more uniform the temperatures are kept the better the results.

It is believed that the tendency is toward the "holder" process of pasteurization for cream and also toward pasteurizing directly in the ripening vats. Some types of modern ripening vats are provided with spiral coils or disks through which low-temperature water or

brine is circulated, and the temperature is controlled by regulating the flow. The coils are rotated at a constant speed, thereby insuring even temperature throughout the mass of cream. With an arrangement of this kind the temperature of the cream is raised to 140° and allowed to stand for 30 minutes, when it is cooled quickly to about 65° by circulating cold water through the coils. The cream is allowed to stand at this temperature until it is ripened. The temperature must again be reduced to 52° to 60° before the ripened cream is run into the churn. This latter reduction of temperature of about 10° is accomplished by low-temperature brine or ice water.

The proper churning temperatures also vary, but in summer from 52° to 54° is considered to be an average, while in the winter, the churning temperature rises to about 56° to 60° .

The term "starter" is used to designate a quantity of milk in which lactic acid-forming bacteria have been cultivated until it contains large quantities. This starter is added and seeds the cream with great numbers of these cultivated bacteria, which by their growth cause the acid formation to progress rapidly and in a more definite manner than without the addition of the starter.

In the preparation of the starter a quantity of good skimmed milk is taken and heated to a temperature of 185° to 190° and allowed to stand for 30 minutes, after which it is cooled down to 70° or 80° . To this milk is added the mother starter, which is a pure culture of the desired bacteria, in sufficient quantity to sour the skimmed milk in about the desired time. In order to develop the proper flavor, the perfect control of the temperature of the starter milk is necessary. Where the starter is made every other day it is preserved by holding at a temperature of 50° or below. The amount of starter usually required is one gallon for every 10 or 15 gallons of cream. The cooling of the starter from the pasteurizing temperature, 185° to 190° , is usually done by circulating well water through the jacketed space surrounding the starter can; consequently, mechanical refrigeration is only required to preserve the starter in storage.

An ample supply of pure cold water for working the butter is very desirable. The average temperature of well water, especially in the South, is too high for washing butter; consequently it becomes necessary to cool the water to a temperature sufficiently low for this work. The temperature of the water used in washing the butter depends to a certain extent upon the character of the butter. In summer weather, wash water at a temperature of about 52° to 56° is considered satisfactory, while in winter, the temperature may be as high as 60° to 62° . It may be generally stated that the temperature of wash water should not vary more than from one to three degrees below the temperature of the buttermilk.

The cooling of wash water is done in tanks which should be located at an elevation sufficiently great to command the butter worker and churn. The cooling is done either by direct expansion or brine coils submerged in the tank. The capacity of the tank necessary will vary with the size of creamery, but tanks holding from 100 to 500 gallons are of sufficient capacity for the majority of creameries.

In the medium and smaller sized creameries a cold storage is provided of sufficient capacity to hold at least a week's output of butter, as it is not always convenient to make shipment as soon as made.

The question of the proper temperature at which butter should be stored is an open one. It is at its best, however, when freshly made, and its fine quality will last only a few days if kept at the ordinary summer temperatures. Experiments show that the changes which take place in butter and cause rancidity and other disagreeable flavors diminish as its temperature is reduced. Consequently its quality is determined by the temperature at which it is held rather than the time. The quality and flavor of butter will eventually deteriorate under any storage temperature that has so far been tried. Therefore, the effect of storing at different temperatures is only a matter of degree and not of absolute stoppage of all changes.

It is believed that in the individual creamery where not over a week's output is in storage at one time, that a temperature of 32° F. is satisfactory where mechanical refrigeration is available. Where refrigeration is accomplished by using ice, it is impracticable to get so low a temperature, 50° to 45° F. being about the temperature maintained in the best ice refrigerators.

LOCAL CREAMERIES.

Local creameries are either cooperative or privately owned, and receive milk or cream, or both, from the immediate vicinity or from their auxiliary creameries located near by. Their equipment usually consists of pasteurizers, coolers, churns, etc., with the necessary motive power apparatus, and often separators for handling the whole milk, which may be delivered direct to the creamery instead of to the auxiliary creamery. Often the local creamery is not supplied by auxiliary creameries but depends on the farmers of the immediate vicinity who deliver the whole milk directly to the creamery, in which case the local creamery does all the separating. Probably the majority of local creameries are supplied with cream separated on the farm and delivered by the patrons to the creamery, or collected by cream haulers.

In a local creamery making, say, 2,000 pounds of butter daily the method of operation is as follows:

In the morning the cream which has been allowed to stand and ripen overnight in the ripening vats is emptied into the churns and the churns started. About three-quarters of an hour is required

to do the actual churning, and about 20 minutes more to work the butter. During this time the cream ripeners are washed.

The arriving cream from the auxiliary creameries or farms is weighed, sampled, and pasteurized. The pasteurizing may be done either in the ripening vats or in a separate pasteurizing machine. When the cream is pasteurized in the ripening vats it is cooled by running cold water through the coils and the jacket surrounding the vat. When a separate machine is used, the cream is run over a cooler on its way to the ripening vats, where it is held at the proper temperature for ripening from 18 to 20 hours. After the churning is finished and the butter packed in tubs or boxes and stored in the refrigerator, the churns and other apparatus are washed as well as the floors of the building. The afternoons are usually given up to office work, making repairs, etc. The machinery is, therefore, operated only about eight hours a day; consequently, the refrigerating machine should be of sufficient capacity to do the work in about eight hours' time.

The size of the room necessary to accommodate a creamery making 2,000 pounds of butter daily is about 10 by 10 by 10 feet, giving 600 square feet surface. Assuming that the walls, floors, and ceiling are insulated for a heat transmission of 2 B. T. U. per square foot per 24 hours for each degree of difference between the inside and outside temperature, then with an average outside temperature of 80° F. the refrigeration necessary is:

	B. T. U.
Removing heat coming through walls, floors, and ceiling, $600 \times 2(80^\circ - 32^\circ) \dots$	57, 600
Cooling cream, $5,500 \times .90(75^\circ - 50^\circ) \dots$	123, 750
Cooling butter, $2,000 \times .5494(58^\circ - 32^\circ) \dots$	28, 568
	209, 918

In view of the fact that the greater part of the refrigeration is required for cooling the cream, an increase of 25 per cent to compensate for losses of various kinds should be ample. Therefore, the total amount of refrigeration necessary in 24 hours is 262,398 B. T. U. But as the work is to be accomplished in 8 hours, the capacity of the machine necessary is: $\frac{262,398 \times 3}{288,000} = 2.73$ tons, say, 3-ton machine.

The cooling of the cream will take about one hour and the amount of brine necessary, allowing a 10° rise in brine temperature, is $\frac{123,750}{520} = 238$ cubic feet, without the aid of the machine at the time. With the machine running during the time the cooling takes place, the cubic feet of brine necessary is $\frac{123,750 - 36,000}{520} = 168$. After the cream is cooled and run into the vats for ripening, the brine is cooled down for holding over the room temperature during the

night. The heat that will come through the walls, floor, and ceiling during the shutdown period is $\frac{57,600 \times 16}{24} = 38,400$ B. T. U. and the temperature of the brine will rise $\frac{38,400}{168 \times 52} = 4.4^\circ$.

The curves in figure 36 show the approximate size and cost of belt-driven refrigerating plants for various sized creameries. The curves are estimates under average conditions of operation and were checked by a large number of such plants now in operation.

In the construction of the cold-storage room great care should be exercised in selecting and installing the insulation. It has been shown under the section on insulation that three-fourths of the work

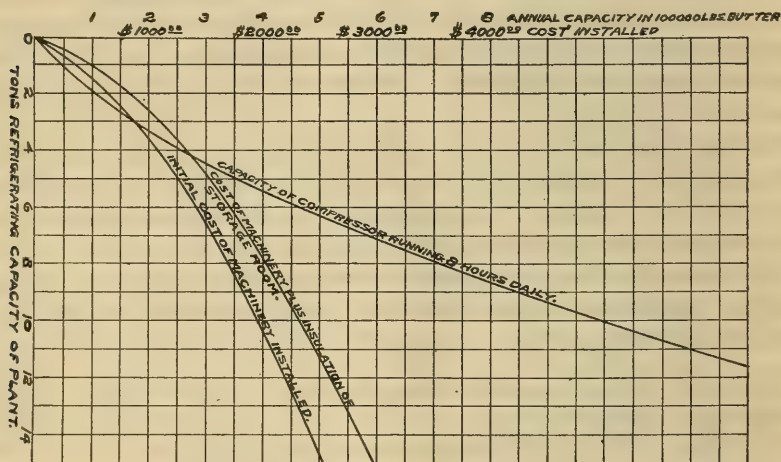


FIG. 36.—Curves showing the approximate size and cost of belt-driven compressors for various size creameries.

of refrigeration required for cold storage is utilized in “pumping out,” so to speak, the heat that comes through the walls, floor, and ceiling of the room. In addition to the insulating value of modern insulation, it serves as a protection to the goods in storage in case of fire, due to its slow burning qualities.

It is often advantageous in creamery cold storage to provide extra rooms for the purpose of storing eggs and poultry. They should never, however, be stored in the same compartment with the dairy products, as they will impart a taint to these goods.

CENTRALIZED CREAMERIES.

Centralized creameries, as the name implies, are established for the purpose of handling and manufacturing into butter the cream received from many outlying stations, or from direct shippers. The outlying stations are usually termed “cream-buying stations” and often located at a distance of 100 miles or more from the main creamery.

The centralized, or main, creamery is usually located on a railroad or, better still, at the intersection of two or more railroads. The cream-buying stations are distributed along the lines of the railroads in the most favorable locations for collecting cream. The collected cream is shipped to the centralized creamery, the time of arrival, of course, depending upon train schedules. In some instances cream arrives at practically all hours, both day and night. As soon as received at the creamery, the cream is sampled, weighed, and pasteurized. After pasteurization the cream is cooled and run into vats where it is held until the following morning, when it is churned. Generally the churning and the working of the butter take place in the forenoon, although in some instances this work is done at any time that happens to be the most convenient.

Usually the cream is ripe when received, and if churning is to be delayed the temperature of the cream is lowered to a point where the development of acid bacteria practically stops, at which temperature it is held until ready to churn.

In case a force is kept on duty continuously, the refrigerating plant may be operated 24 hours a day; hence, the size of the plant is materially reduced from that required if the plant were operated only 8 hours. Generally speaking the methods of operation employed in the centralized creameries are very similar to those of the local creamery, except they are on a more extensive scale and only cream is handled.

CREAM-BUYING STATIONS.

Cream-buying stations are established for the purpose of supplying the centralized creameries with cream by collecting the cream directly from the farmers and shipping to the main creamery. These stations are located at suitable points along the railroads in close proximity to a large number of farms. The cream is brought to the buying stations by the farmers, where it is received by the agent of the main creamery and held until a sufficient quantity is on hand to justify shipping. Generally no provision is made for cooling the cream at the buying stations.

In figure 37 are given the weights of a gallon of cream containing varying percentages of fat.

COOLING CREAM IN AUXILIARY CREAMERIES.

The auxiliary creameries, commonly known as skimming stations, are erected for the purpose of furnishing cream to the main creamery without the inconvenience of having to haul the raw milk a long distance. By separating the cream from the milk in the auxiliary creamery and hauling only the cream to the main creamery a great saving in time and labor is effected, as it is necessary to haul only about an average of 13 per cent of the total weight of the whole milk.

The auxiliary creameries are located at suitable points in the country surrounding the main creamery, where they are in close proximity to a number of farms. Where a creamery draws its supply of milk from a large and scattered area, the auxiliary creameries are essential to its economical operation.

The milk is brought to the auxiliary creamery by the farmers early in the morning and it is immediately sampled, weighed, and separated. The skimmed milk is returned to the farmers, who haul it home for feeding to stock, and the cream is run from the separator over a cooler, caught in cans, and carried to the main creamery, where it is ripened and made into butter. In some States the skimmed milk is heated before being delivered to the farmers to a temperature of 180° F. in order to destroy any disease-bearing bacteria that might be transmitted to stock by feeding on the milk.

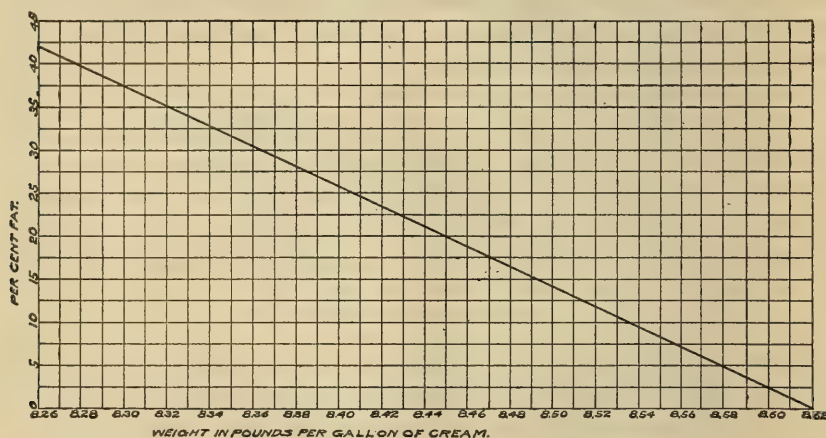


FIG. 37.—Weight of a gallon of cream at 68° F. with varying percentages of fat.

Before separating the whole milk its temperature is raised to 90°. It is then run through the separator, coming out at a slightly lower temperature than that at which it entered. It should be immediately run over some form of cooler and its temperature reduced to an average of about 40°, at which temperature it should be run into insulated cans and carried to the main creamery, where it is ripened and made into butter. It is practicable to reduce the temperature of the cream by the water section of the cooler to about 60° in the Northern States, but in the Southern States a temperature of 70° is about as low as it is practicable to lower the temperature by well water. From the temperature at which the cream leaves the water section of the cooler to a final average temperature of 40° the cooling is done in the more modern creameries by circulating low-temperature brine or water through the coils. In those localities where natural ice is available at a small cost the cooling is generally done by employing a mixture of salt and ice. In the Southern States, however, where natural ice

is not available and the cost of manufactured ice is too great for economical use, mechanical refrigeration is desirable in order to reduce the temperature of the cream to a point where it can safely be carried to the main creamery.

Due to the development of the hand separator, by the use of which the farmer is enabled to separate his milk on the farm, the auxiliary creamery is fast being done away with. This arrangement, however, places the responsibility of properly cooling the cream upon the farmers before it is hauled or shipped to the creamery. What has been said on the subject of cooling milk on the farm is, of course, applicable to the cooling of cream, and as the weight of cream is only about 13 per cent of that of the whole milk, the cooling is a comparatively easy matter.

Where the separating is done at the auxiliary creamery the milk is first heated to about 90° before being run through the separator. The temperature of the cream is first reduced by the well-water section of the cooler to approximately 60° .

Assuming that the auxiliary creamery handles 1,500 pounds of cream daily through the summer months, and the temperature of the cream when received is 60° , and that it is cooled to an average temperature of 40° , the refrigeration necessary to cool the cream is $1,500 \times .90(60-40) = 27,000$ B. T. U. But there is the loss in cooling brine, radiation, etc., that must be taken into consideration.

Owing to the variation due to poor workmanship, the arrangement of the apparatus, etc., it is impracticable to calculate very closely on the amount of refrigeration that will be lost. Therefore it is customary to allow a certain amount to cover this loss, which usually varies from 25 to 50 per cent. In the case under consideration 25 per cent would be ample. During the summer months the machine would be run about 6 hours per day; therefore the size of machine necessary would be $\frac{27,000 \times 1.25 \times 4}{288,000} = 0.5$ ton.

A cubic foot of calcium-chlorid brine will absorb about 52 B. T. U. in rising 1° F., and allowing a 10-degree rise in brine, 30 to 40° , each cubic foot will absorb $52(40-30) = 520$ B. T. U. Therefore the volume of brine required for cooling the cream is $\frac{27,000}{520} = 52$ cubic feet, providing the machine is not running during the cooling process. But with the machine in operation the volume of brine will be considerably less. A half-ton machine is capable of extracting 6,000 B. T. U. per hour. Consequently as the machine is run during the two hours of cooling it will extract 12,000 B. T. U. and the volume of brine necessary will be $\frac{(27,000 \times 1.25) - 12,000}{520} = 41.8$ cubic feet.

As the amount of heat that will come through the walls of the brine tank is directly proportional to the exposed outside surface, and as

the cost of insulation also varies in the same proportion, it is obvious that the brine tank should be constructed in the form of a cube which gives the least exposed surface for a given volume of any form of rectangular tank.

The brine tank should be in the form of a cube with 3-foot 8-inch sides, giving a surface of 80 square feet. The tank should be insulated for a heat transmission of not over 2 B. T. U. per square foot, per 24 hours per degree difference between the inside and outside temperature.

MARKET CREAM PLANT.

The market cream plant, as the name implies, handles only sweet cream for the market. The plant is usually provided with churns in order to make butter from any soured cream that may accumulate, otherwise the equipment consists of that necessary for pasteurizing and cooling.

The method of operating a plant of this kind is essentially the same as that employed in operating a regular local creamery; that is, the plant is located on a railroad where good connections are had with the markets. The milk or cream is received from the producers or auxiliary creameries, usually early in the morning, and is pasteurized and refrigerated immediately. In a market cream plant it is imperative that the work be done quickly and thoroughly in order to get the cream on the market in perfect condition. In this type of plant refrigeration is of the utmost importance, as the safe handling of the cream depends more on the proper cooling than any other one feature of the business.

The amount of refrigeration required in the market cream plant is of course considerably more than that for a creamery handling the same amount of cream for butter making, as the temperature maintained for market cream is considerably lower. In ripening cream for butter making it is seldom that its temperature is allowed to go below 50° F., about 65° F. being the usual ripening temperature. With cream intended for the market, however, a temperature of just above the freezing point is desired. Shipping facilities often require the holding over of one day's supply of cream to the morning of the following day, consequently suitable provision for cold storing must be provided.

What has already been said on the cooling, storing, and shipping of milk is of course applicable to cream.

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Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
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TESTS OF SELECTIONS FROM HYBRIDS AND COMMERCIAL VARIETIES OF OATS.

By C. W. WARBURTON, *Agronomist in Charge of Oat Investigations*, and L. C. BURNETT and H. H. LOVE, *Collaborators, Office of Cereal Investigations* (in cooperation with the Iowa and Cornell University Agricultural Experiment Stations).²

INTRODUCTION.

The breeding of oats was begun by the Bureau of Plant Industry in 1902. In that year Mr. Jesse B. Norton, then of the Plant-Breeding Laboratory, grew a collection of varieties at the Arlington Experimental Farm, near Washington, D. C., and made a large number of crosses. The resulting seed was planted in the spring of 1903 at Willey, Ill. The following year the work was transferred to the vicinity of Bloomington, Ill., where it was conducted from 1904 to 1908.³ Field-plat tests of a number of commercial varieties were also made at Willey in 1903 and during the earlier years of the work near Bloomington. The experiments were confined to nursery tests in 1907 and 1908. Pure-line selections were made from these plats of commercial varieties, and material for crossing was also taken from them. The first selections were made from the hybrids in 1904, and reselections were made from time to time as further breaking up was apparent. All these selections were first grown in head rows, and those which appeared to be most desirable were grown in succeeding years in nursery rows of uniform length for comparative tests.

In 1907 considerable numbers of the selections were sent to the Kentucky, Iowa, and Cornell University (New York) agricultural

¹ This bulletin is intended for the use of farmers, agronomists, and cereal breeders, to whom the comparative data on selections from hybrids and commercial varieties should be of interest. It is adapted to the northern part of the United States as far west as the Missouri River.

² The work in cooperation with the Iowa Agricultural Experiment Station has been under the direct charge of Mr. L. C. Burnett, while that in cooperation with the Cornell University Agricultural Experiment Station has been under the direction of Dr. H. H. Love. The results of the work at these stations have been prepared for publication by Messrs. Burnett and Love, respectively. The remainder of the bulletin has been prepared by Mr. C. W. Warburton.

³ Mr. Norton and the writer desire to acknowledge their indebtedness to Messrs. Deane N. and J. F. Funk for facilities furnished and for their hearty cooperation in the work near Bloomington.

experiment stations for testing. In that year, on the resignation of Mr. Norton from the United States Department of Agriculture to accept a position in Cornell University, the writer was placed in charge of the oat-breeding experiments in connection with his other work with oats in the Office of Cereal Investigations. In 1909, the work in Illinois having been discontinued, the Iowa station was made the headquarters for the testing of the oat selections. Since that time the more extensive tests have been made at the Iowa and Cornell University experiment stations, while smaller numbers of the selections have been tested at several of the other State stations, as detailed in the pages which follow.

It is the purpose of this bulletin to present the results of these preliminary tests, as indicative of the varieties and varietal combinations which are most likely to prove of value in the various sections where the tests have been conducted.

PARENTAGE OF THE SELECTIONS.

Three lots of hybrids were made by Mr. Norton, the first at the Arlington Experimental Farm in 1902, the second on the Funk brothers' farms at McLean, Ill., in 1905, and the third at the latter place in 1906. The hybrids resulting from the first lot of crosses have been quite widely tested. Those of the second and third lots have been grown only at the Iowa station and have not yet been tested long enough to report results. A considerable number of combinations were made in each of the years, but only those which are represented in the nursery tests reported in this bulletin are given here.

HYBRIDS.

Of the 52 varietal crosses made in 1902 only 19 are represented in the records after 1906, the others either having failed or having been discarded because of evident inferiority. The varietal combinations which are still represented in the nursery tests, with the series numbers by which they are designated, are as follows:

- | | |
|--|--|
| 3. Golden Giant × Asia Minor Rustproof. | 34. Burt × Sixty-Day. |
| 8. Danish Island × Asia Minor Rustproof. | 38. Burt × Clydesdale. |
| 25. European Hull-less × Garton Tartar King. | 41. Asia Minor Rustproof × Clydesdale. |
| 27. Garton Tartar King × Clydesdale. | 42. Asia Minor Rustproof × Clydesdale. |
| 28. Silvermine × Danish Island. | 44. Asia Minor Rustproof × Garton Tartar King. |
| 30. Burt × Clydesdale. | 45. Asia Minor Rustproof × Silvermine. |
| 31. Burt × Red Rustproof. | 48. North Finnish Black × Burt. |
| 32. Burt × Early Champion. | 49. Sixty-Day × Clydesdale. |
| 33. Burt × Burt. | 50. Sixty-Day × Probsteier. |
| | 51. Sixty-Day × European Hull-less. |

COMMERCIAL VARIETIES.

In 1904 pure strains from commercial varieties were started from heads selected from the field plats grown that year in cooperation with the Funk Bros. Seed Co., at Shirley, Ill. The series numbers of these pure-line selections are as follows:

62. Sixty-Day.	125. Silvermine (Great American).
63. Burt.	131. Pringle Progress.
115. Red Rustproof.	132. Sixty-Day.
117. Early Champion (Alaska).	137. Early Champion.
118. Silvermine (Musselshell).	138. Early Champion.
119. Probsteier.	142. Goldmine.
120. Silvermine (Great Dakota).	165. Sixty-Day.
123. Welcome.	5938. Sixty-Day.
124. Silvermine.	

THE SYSTEM OF NUMBERING.

As shown in the preceding paragraphs, each combination of varieties which was made was given a series number. Thus, all hybrids in which Sixty-Day, S. P. I. No. 5938, was the female parent and Clydesdale, P. B. No. 8, was the male parent were of series 49. Each combination of individuals was designated by a letter, as a, b, c, etc. For instance, if crosses were made on three plants of Sixty-Day oats, using the same or different plants of Clydesdale as the male parents, these individual combinations were numbered 49a, 49b, and 49c. Each plant produced in the F_1 generation was numbered consecutively for each combination of individuals, as 49a1, 49a2, 49a3, 49b1, etc. This number is always written as a unit. As individual plant selections were made, these were given serial numbers, this number being separated from the hybrid plant number by a dash. As subsequent selections were made, these were also numbered serially. Thus, 49a2-20-7 is pure-line selection No. 7 from pure-line selection No. 20 from plant No. 2 of the hybrid combination No. 49a, Sixty-Day $\times$ Clydesdale. If a reselection was made after a lapse of one or more years without selection, this lapse is indicated by xx, as 49a2-20-xx-7. If a bulk selection was made, the selection number is written in Roman instead of in Arabic, as 51a1-15-I.

The selections from commercial varieties were numbered in the same manner as those from the hybrids. Each stock was given a series number, but the numbers of pure-line selections from commercial varieties do not contain a letter followed by a numeral, as is the case in all hybrid numbers. Each individual selection bears the series number followed by a serial number within the series and separated from it by a dash, as 125-17. Bulk selections, as in the hybrids, are indicated by Roman numerals. Thus, 62-II-18-1 is the progeny of plant No. 1, selected from the progeny of plant No. 18, which in turn was selected from Bulk Selection II from the original

Sixty-Day stock. By this system of numbering, the common parentage of strains is shown at a glance.

MAKING THE SELECTIONS.

In both the hybrids and commercial varieties selections of individual heads were made, the selections being based on size of head, vigor of plant, size and color of grain, and other characters, as desired. The seed from each head was planted in a head row, usually a row 5 feet long. These rows were then numbered serially, to indicate their location in the nursery, while the selection number indicated the parentage of the selection. Only those rows which appeared to be of value were harvested. Usually not more than 10 per cent of the head selections which are made are retained after the first year's test in head rows. No doubt some valuable strains are lost in this way, but the success of work of this kind depends very largely on the judgment of the breeder. Where space and funds are more or less limited it appears to be better to make a large number of head or plant selections, cull these carefully in the head rows, and put only those that appear to be best in the comparative-yield test, going back to the original stock or drawing on new sources for additional material for head rows as opportunity offers rather than to select a comparatively small number of individuals and retain all these in the test for several years. It is only by handling large numbers of individuals and by culling very carefully that one can hope to gain the desired ends in cereal breeding.

The strains which were selected from the head rows were tested first at McLean, Ill., on the farm of Mr. Deane M. Funk. Later, considerable numbers of them were tested at the Iowa and Cornell University stations, and less inclusive tests were made at a number of other experiment stations. The results of these tests are given in the following pages.

TESTS AT M'LEAN.

METHOD OF TESTING.

The tests at McLean, Ill., were made in rod rows according to a method devised by Mr. Norton.¹ Briefly, the strains included in the comparative test at McLean were planted in rows 17 feet long and 1 foot apart, with every twentieth row as a check row. A pure-line selection of Sixty-Day, 62-II-19, was used as a check in 1907; a selection of this strain, 62-II-19-3, was used in 1908. The rows were 17 feet long, so that each row occupied 17/43560 or approximately 1/2560 of an acre.² As there are 512 ounces in a bushel of

¹ Norton, J. B. Notes on breeding oats. American Breeders' Association, Report 3, pp. 280-285, 1907. The method is described somewhat more in detail by H. J. Webber in Plant-breeding for farmers (New York, Cornell Agricultural Experiment Station, Bulletin 251, pp. 318-319, 1908) and by C. W. Warburton in Improvement of the oat crop (U. S. Department of Agriculture, Bureau of Plant Industry, Circular 30, pp. 6-8, 1909).

² The first fraction is equal to 0.00039027 acre, while the second is 0.00039063 acre.

oats, a yield of 1 ounce from one of these rows is at the rate of 5 bushels to the acre. Similarly, the rate of seeding is easily calculated; at the rate commonly in use in the corn belt, 2.5 bushels to the acre, one-half ounce of seed is required for each row.

RESULTS OF THE TESTS.

The tests at McLean in 1907 included 419 selections from hybrids and 82 pure-line selections from commercial varieties. In 1908, 378 hybrids and 69 pure-line selections were grown. Only 177 of the selections from hybrids and 51 of those from commercial varieties were grown both years. Table I summarizes the tests of these two years, the strains being grouped and averaged according to their parentage. This table shows the number of strains of each series which were grown each year and the number which were included in both years' tests, with the average yields in bushels to the acre.

TABLE I.—Average yield per acre of each series of hybrids and commercial varieties of oats grown in nursery tests at McLean, Ill., in 1907 and 1908, showing also the number of strains of each series grown.

Series.	Grown in 1907.		Grown in 1908.		Grown both years.	
	Number of strains.	Average yield.	Number of strains.	Average yield.	Number of strains.	Average yield.
		<i>Bushels.</i>		<i>Bushels.</i>		<i>Bushels.</i>
No. 3.....	5	43.96	3	32.70	3	38.00
No. 8.....	21	49.47	18	40.77	10	48.62
No. 25.....			2	15.48		
No. 26.....	2	26.00				
No. 27.....	5	34.47	9	33.11	2	36.37
No. 28.....	1	35.80	1	31.55	1	33.67
No. 30.....	63	44.32	36	36.04	20	44.65
No. 31.....	5	38.27	8	40.09	2	44.58
No. 32.....	2	46.32	2	39.90	2	43.11
No. 33.....	29	48.58	10	43.16	10	47.67
No. 34.....	59	49.82	28	43.08	16	47.74
No. 35.....	1	33.75				
No. 38.....	7	43.59	4	33.21	4	38.57
No. 41.....	3	32.20	3	37.62		
No. 42.....	12	39.69	3	39.63	2	41.13
No. 44.....	4	37.09	4	33.46	1	35.77
No. 45.....	5	38.11				
No. 48.....	7	37.65	15	46.08	3	45.12
No. 49.....	135	46.14	177	38.07	71	45.14
No. 50.....	47	50.87	42	39.42	26	46.82
No. 51.....	6	40.10	13	26.33	4	37.34
No. 62.....	16	59.41	17	44.23	13	52.90
No. 63.....	6	56.55	5	48.43	5	52.83
No. 115.....	1	45.60				
No. 117.....	4	48.65	3	25.58	3	36.18
No. 118.....	3	37.55	1	28.15	1	34.15
No. 119.....	4	38.32	1	29.55	1	32.27
No. 120.....	4	38.95				
No. 123.....	1	42.95	1	32.25	1	37.60
No. 124.....	2	41.70	2	25.25	2	33.47
No. 125.....	13	38.66	8	33.66	8	35.72
No. 131.....	7	49.20	7	40.74	5	47.30
No. 132.....	3	61.72	8	46.42	3	56.11
No. 137.....	9	47.19	4	26.50	2	39.15
No. 138.....	6	49.35	4	26.42	4	38.50
No. 142.....	1	51.25	1	21.50	1	36.37
No. 165.....	1	56.40	1	36.85	1	46.52
No. 5938.....	1	46.30	1	28.45	1	37.37
Burt.....			5	41.65		
Total.....	501		447		228	
Average.....		46.42		38.25		45.04

THE MOST PROMISING SELECTIONS.

The highest yielding selections were all from commercial varieties, as follows: 62-II-19-3 from Sixty-Day, 58.27 bushels to the acre; 63-I-4 from Burt, 57.7 bushels; 62-II-6-3 from Sixty-Day, 57.37 bushels; 132-3-1 from Sixty-Day, 57.2 bushels; and 62-II-19-1 and 132-2 from Sixty-Day, 56.57 bushels. Practically all of the 25 highest yielding strains in these tests were derived from the Sixty-Day or Burt or a combination of these two varieties. Of the selections grown in both 1907 and 1908, 17 pure lines of Sixty-Day averaged 52.55 bushels, 15 strains of Burt averaged 49.39 bushels, and 16 strains of series 34 averaged 47.74 bushels. These yields were in excess of those of all other series except series 8, Danish Island × Asia Minor Rustproof, 10 strains of which averaged 48.62 bushels. The 25 strains which produced the highest average yields for the two years are shown in Table II.

TABLE II.—Average yield per acre of 25 highest yielding oat selections grown in nursery tests at McLean, Ill., in 1907 and 1908.

Rank.	Selection No.	Parentage.	Average yield.	Rank.	Selection No.	Parentage.	Average yield.
			<i>Bushels.</i>				<i>Bushels.</i>
1	62-II-19-3.	Sixty-Day	58.27	15	132-3-2....	Sixty-Day	54.55
2	63-I-4.....	Burt.....	57.70	16	30a2-6-15..	Burt × Clydesdale.	54.35
3	62-II-6-3..	Sixty-Day	57.37	17	62-II-19....	Sixty-Day	53.95
4	132-3-1....	do.....	57.20	18	49a2-13....	Sixty - Day × Clydesdale.	53.72
5	62-II-19-1.	do.....	56.57	19	8a2-6-5....	Danish Island × Asia Minor Rustproof.	53.25
6	132-2.....	do.....	56.57	20	50a1-15-5..	Sixty-Day × Probsteier.	53.15
7	34a1-12-3..	Burt × Sixty-Day.	56.50	21	62-II-18-1.	Sixty-Day	53.12
8	8a2-6-6....	Danish Island × Asia Minor Rustproof.	56.35	22	50a1-20-7..	Sixty-Day × Probsteier.	53.10
9	63-I-1.....	Burt.....	56.05	23	63-I-7.....	Burt.....	53.00
10	49a1-7.....	Sixty - Day × Clydesdale.	55.97	24	49a2-18....	Sixty - Day × Clydesdale.	52.95
11	49a1-12....	do.....	55.57	25	62-II-6-1-1	Sixty-Day	52.80
12	62-II-17-1.	Sixty-Day	55.37				
13	34a1-13-1..	Burt × Sixty-Day.	54.82				
14	8a2-6-4....	Danish Island × Asia Minor Rustproof.	54.60				

Five of the 10 strains which produced the highest yields for the two years were pure-line selections of Sixty-Day, 2 were pure-line selections of Burt, 1 was a selection from a hybrid of these two varieties, 1 was a selection from a hybrid of Danish Island × Asia Minor Rustproof, and 1 was a selection from a hybrid of Sixty-Day × Clydesdale. Thus, of these 10 strains, 7 were pure lines from Sixty-Day or were selections from hybrids in which that variety was a parent, 3 were selections from Burt or from hybrids in which Burt was a parent, and only 1 was unrelated to either of these varieties. These 10 strains averaged 56.85 bushels to the acre, as compared with an average of 45.04 bushels for the 228 strains tested. The 25 highest yielding strains averaged 55.07 bushels to the acre. Of these 25 strains 15 were selections of Sixty-Day or

Burt or from a hybrid of these two varieties, 18 were pure lines of Sixty-Day or were selections from hybrids in which that variety was a parent, 6 were pure lines from Burt or selections from hybrids containing that variety, and only 3 represented neither variety. It is apparent, therefore, that Sixty-Day and Burt are valuable varieties for central Illinois, a conclusion which is in agreement with varietal tests at the Illinois experiment station.

COMPARISON OF SELECTIONS FROM HYBRIDS AND COMMERCIAL VARIETIES.

In 1907, 82 selections from commercial varieties exceeded 419 selections from hybrids in average yield to the acre by 2.57 bushels, or 5.59 per cent. In 1908, 69 selections from commercial varieties averaged 0.07 bushel, or 0.18 per cent more than 378 selections from hybrids. In all the 948 tests made in the two years, 151 pure lines from commercial varieties averaged 1.56 bushels, or 2.69 per cent more than 797 selections from hybrids. Of the 228 strains which were tested both years, however, 51 pure lines from commercial varieties averaged 0.56 bushel, or 1.24 per cent, less than 177 selections of hybrid parentage. Of the 10 highest yielding strains, 7 were selections from commercial varieties and 3 were from hybrids, while of the 25 highest, 13 were from commercial varieties and 12 from hybrids. This slight superiority for the selections from commercial varieties over those from hybrids is probably due largely to the fact that a large proportion of the former were from two varieties particularly suitable to central Illinois, Sixty-Day and Burt, while one or both parents of many of the hybrids were varieties not so fully adapted to the conditions.

TESTS AT THE IOWA AGRICULTURAL EXPERIMENT STATION.

INTRODUCTION.

The cooperative investigations for the improvement of the oat crop by the Iowa Agricultural Experiment Station and the Bureau of Plant Industry were begun in 1903. In the earlier years of the cooperation a study was made of the general conditions and methods of production. In 1907, 66 of the better strains from the oat nursery at McLean, Ill., were secured for testing. When the work at McLean was discontinued in 1909, the strains retained from the earlier trials at that place, 381 in all, were added to the nursery at Ames, Iowa.

CONDITIONS OF THE TESTS.

The plats used in all nursery tests at the Iowa station have each been confined to an area of 30 square feet. Each selection is planted in duplicate in rows 15 feet long and 1 foot apart. These rows are the unit of the nursery. Each is maintained as a separate plat until thrashing time, when the duplicates are united and yields and other

data on the grain are taken from the combined product. Figure 1 shows the method of harvesting the selections, while figure 2 is a view of the oat nursery when the harvest was about completed.

The soil used in the nursery work has varied somewhat, but in general may be termed rolling prairie upland. In 1907, 1908, and 1911 the tests were made on a dark prairie-loam soil. In 1909, 1910, and 1912 the fields varied from dark prairie loam to a much lighter colored gravelly loam.

The preceding crop each season except 1910 and 1911 was corn. In 1910 the nursery followed the oat varietal plats, while in 1911 it followed barley. When the nursery has followed corn the stalks have been removed and the land plowed in the fall. When following small



FIG. 1.—Field of oats, showing the method of harvesting selections when grown in nursery rows.

grain, it has been necessary to plow in the summer and to cultivate, in order to germinate all volunteer grain before seeding time the following season.

The climatic conditions have been far from uniform during the period covered by the tests reported in this publication. The years 1907 and 1908 were very wet. In 1909 the yields of all the early and medium selections were reduced, because they were blown down by a severe wind and rain storm before the grain filled. The 1910 crop was grown almost entirely from moisture that fell before May 1. The 1911 crop was grown under abnormally dry conditions and was badly damaged by a hot wind about July 1. The 1912 crop was produced under the most favorable conditions of any of the six, with the exception that two windstorms lodged many of the selections.

THE HIGHEST YIELDING SELECTIONS.

Of the 64 selections which have been tested at the Iowa station for six years, the five with the highest average yield to the acre follow: Welcome selection 123-5, 48.5 bushels; selection 50a1-24 from the hybrid Sixty-Day $\times$ Probsteier, 47.8 bushels; and Sixty-Day selections 62-II-6-3, 47.2 bushels, and 62-II-19 and 62-II-19-1, 46.5 bushels each. Of the 10 highest yielding strains four are selections from Sixty-Day, two from Burt, two from a hybrid of two strains of Burt, one from Welcome, and one from the hybrid Sixty-Day $\times$ Probsteier. Only three of these 10 selections have been derived from hybrids. Eight of the 10 highest yielding selections are early in maturing, the average date of ripening for the six years being before July 15. The highest yield obtained in the 4-year test is



FIG. 2.—Oat nursery at the Iowa experiment station when harvesting was almost completed, showing the method of protecting the bundles from mixture and from injury.

that of selection 34a1-12-1-1 from the Burt $\times$ Sixty-Day hybrid, 72 bushels to the acre. This high average is due largely to the extremely high yield of this selection in 1912, 117 bushels, while other selections from the same hybrid which yielded as well in previous years ranged from 60 to 80 bushels. This selection is not yet fixed, as it still shows considerable variation in some characters. This may explain, in part at least, its high yield. It will be further selected in the future.

Six closely related selections from series 8, Danish Island $\times$ Asia Minor Rustproof, ranged from 59 to 64 bushels in average yield. The highest yield obtained from any selection from a commercial variety in this test was 58 bushels from the Welcome selection, 123-5. Of the 25 selections which averaged 54 bushels or more in yield for

the four years, 7 are from series 34, Burt × Sixty-Day; 9 are from series 8, Danish Island × Asia Minor Rustproof; 4 from series 33, Burt × Burt; and 1 each from series 3, Golden Giant × Asia Minor Rustproof; series 49, Sixty-Day × Clydesdale; series 50, Sixty-Day × Probsteier; series 123, Welcome; and series 131, Pringle Progress.

AVERAGE YIELDS FOR THE VARIOUS SERIES.

The most valuable hybrid combinations included in the tests at the Iowa station are series 3, Golden Giant × Asia Minor Rustproof; series 8, Danish Island × Asia Minor Rustproof; series 31, Burt × Red Rustproof; series 33, Burt × Burt; series 34, Burt × Sixty-Day; and series 44, Asia Minor Rustproof × Garton Tartar King. Among the commercial varieties the highest average yields were produced by selections from series 63, Burt; series 123, Welcome; series 125, Silvermine; series 131, Pringle Progress; and series 165, Sixty-Day. The annual and average yields of each series for the four years are shown in Table III.

TABLE III.—*Annual and average yields of each series of oat selections grown at the Iowa station in a 4-year test, 1909 to 1912, inclusive.*

Series No.	Number of selections.	Yield (bushels per acre).				
		1909	1910	1911	1912	Average.
Hybrids:						
3.....	3	62.00	66.33	18.67	63.33	52.33
8.....	16	59.94	69.50	16.62	70.62	54.31
25.....	1	49.00	52.00	5.00	39.00	36.00
27.....	20	47.00	57.20	12.85	52.80	42.40
28.....	1	37.00	62.00	20.00	49.00	42.00
30.....	32	37.22	59.44	18.28	43.59	39.22
31.....	7	47.71	61.29	20.57	59.57	47.43
32.....	2	50.50	45.50	21.00	49.50	41.50
33.....	10	48.90	64.90	18.90	69.80	50.60
34.....	27	47.26	58.19	19.59	68.52	48.41
38.....	2	35.50	54.00	7.50	54.50	38.00
41.....	2	35.00	54.00	7.50	70.00	42.00
42.....	3	34.00	53.33	16.33	60.00	41.00
44.....	1	40.00	65.00	22.00	85.00	53.00
48.....	14	36.21	59.79	17.57	64.93	44.36
49.....	133	34.56	56.97	11.32	61.59	41.28
50.....	34	35.97	61.26	14.23	54.97	41.71
51.....	12	27.58	44.75	11.67	52.17	34.25
Total.....	320					
Average.....		39.06	58.13	14.25	59.43	42.72
Commercial varieties:						
62.....	17	40.29	52.41	22.12	64.12	44.88
63.....	6	41.33	69.50	18.67	62.00	48.00
117.....	3	36.33	59.33	13.00	46.67	38.67
118.....	1	40.00	69.00	14.00	52.00	44.00
123.....	1	51.00	90.00	24.00	65.00	58.00
124.....	1	41.00	77.00	21.00	45.00	46.00
125.....	6	44.00	70.50	16.50	45.50	44.17
131.....	6	40.33	64.00	24.50	61.67	47.67
132.....	8	40.37	69.50	20.50	45.12	44.00
137.....	2	41.50	58.50	19.50	42.50	40.50
138.....	2	45.00	54.00	21.00	48.50	42.00
165.....	2	43.00	67.00	24.50	62.00	50.00
5938.....	1	39.00	50.00	30.00	29.00	37.00
Burt.....	5	38.60	63.20	24.20	55.60	45.60
Total.....	61					
Average.....		40.89	62.46	20.90	55.43	44.92
SUMMARY.						
Hybrids.....	320	39.06	58.13	14.25	59.43	42.72
Commercial varieties.....	61	40.89	62.46	20.90	55.43	44.92
Total.....	381					
Average.....		39.36	59.04	15.31	58.79	43.12

When a comparison is made of all selections from hybrids with all selections from commercial varieties, it is found that the selections from commercial varieties exceed in average yield those from hybrids in three of the four years. The selections from commercial varieties were 1.83 bushels to the acre higher in average yield in 1909, 4.33 bushels higher in 1910, and 6.65 bushels higher in 1911, while the selections from hybrids exceeded in average yield those from commercial varieties by 4 bushels in 1912. The average yield of all selections from commercial varieties for the four years was 2.2 bushels to the acre higher than that of all selections from hybrids. This does not necessarily imply, however, that hybridization is not of value in improving oats or other cereals. In this particular case, most of the selections from commercial varieties were from Sixty-Day, Burt, and Silvermine, varieties which are well adapted to central Iowa conditions. On the other hand, a number of the varieties used in making the hybrids were not so suitable for Iowa; hence, selections from these hybrids could hardly be expected to yield well.

TESTS AT THE CORNELL UNIVERSITY AGRICULTURAL EXPERIMENT STATION.¹

INTRODUCTION.

A series of the selections made by Mr. Norton was furnished to the plant-breeding department of Cornell University at Ithaca, N. Y., in 1907. Field work was begun that year and has been conducted continuously since that date. The experiments have been conducted so long that the crops have been grown under a wide range of seasonal climatic conditions.

METHODS OF TESTING.

The tests have all been made in rows about 1 rod long, though the exact length of the row has varied from time to time. At present the rows are planted 16 feet in length and 1 foot apart. At the time of cutting, 6 inches are cut off each end of the row and discarded, leaving a 15-foot row on which to base the calculations. The ends of each row are cut off so that the effect of the increased nutrition at the ends will not enter into the calculations and affect the results. By using a 15-foot row and weighing the grain in grams the calculated yield in bushels per acre is obtained by multiplying the grams per row by 0.2 (grams per row $\times$ 0.2 = bushels per acre).² The seed required for each row is weighed into a separate envelope before planting time. All seeding is done by hand, and the rows are marked off by hand, using a board 1 foot wide. It has been

¹ The writer desires to acknowledge his indebtedness to Messrs. F. J. Pritchard, E. P. Humbert, and C. E. Leighty, who at various times have rendered valuable assistance in making these tests. Dr. Leighty also assisted in the preparation of the data for publication.

² The factor actually is 0.20006613+.

found that short rows can be sown by hand fairly rapidly, very uniformly, and much more accurately than by machine.

In the beginning of the work only one row of each strain was grown, but it was found that the same strain should be replicated in as many rows in different parts of the field as is feasible. Beginning in 1909, the different strains were replicated several times and have been each year since then. After trying different systems it has been decided to repeat each variety or strain 10 times, as any less number is considered too small. Since the average of all the rows is easily obtainable with 10 as a divisor, it makes it all the more desir-



FIG. 3.—Oat nursery at the Cornell University experiment station, 1912.

able to use this number. Figure 3 shows the oat nursery at the Cornell experiment station in 1912.

In regard to the use of short rows for the testing of strains, it may be said that of all the systems tried this method seems the most accurate. This is especially true on soil which is very non-uniform. It is not safe to draw conclusions from one plat of a variety, as the plat may be very favorably or unfavorably located and the results influenced thereby. On this point attention may be called to the work of Dr. T. L. Lyon.¹ After comparing the errors obtained from rod rows and tenth-acre plats, he concludes:

¹ Lyon, T. L. A comparison of the error in yields of wheat from plats and from single rows in multiple series. *Proceedings, American Society of Agronomy*, v. 2, 1910, p. 38-39, 1911.

The advantage from the small plats is not only in point of accuracy, but also in the area of land required. Seven one-tenth-acre plats covered an area of 30,492 square feet, while 70 of the 17-foot rows (10 rows of each variety) required only 1,190 square feet. The use of the row method in variety testing is commended by the results of this test.

When the crop is ripe and ready for cutting, each row is cut and tagged separately, as shown in figure 4. The rows are then shocked together under canvas to dry for thrashing. The thrashing is done by means of a machine constructed by Mr. H. W. Teeter, superintendent of field work in the plant-breeding department. This consists of a cylinder built into a box lined with galvanized iron. The

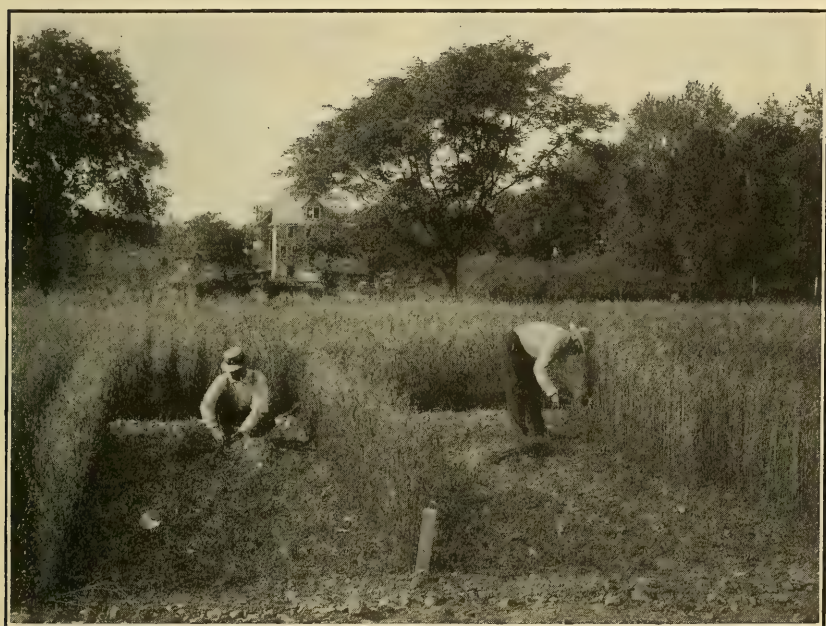


FIG. 4.—Harvesting the 15-foot rows of oats at the Cornell University experiment station.

box is so constructed that the top and back may be lifted up, allowing the grain and straw to shake down on a coarse screen placed over a receptacle which receives the grain, as shown in figure 5. The advantage of lifting the top is that a full view of the interior is possible, so that if any kernels remain behind they can be seen and brushed out. The cleaning is done by means of a small counter seed cleaner.

Since 1908 every tenth row has been used as a check. All the check rows are sown with the same kind of seed, so that a check on soil differences may be obtained. The same variety, selection 50a1-18-4 from the hybrid Sixty-Day $\times$ Probsteier, was used as a check from 1908 to 1911, inclusive, but in 1912 a new check, Canada

Cluster, was used. This is a standard variety for the State of New York. These check rows, however, were not used in computing the yields reported herein, which are the actual yields of the various strains.

SOIL CONDITIONS.

The tests have been made on a soil of the Dunkirk clay-loam type, except in 1908, when the planting was made on a gravelly loam. In 1910 a duplicate series of tests was also grown on the gravelly loam in order to see whether there was any difference in the results from the two types of soil. As the experiments have progressed, an effort has been made to make the conditions uniform. Ordinary



FIG. 5.—Side view of the machine used in thrashing rows of oats at the Cornell University experiment station.

cultural conditions were duplicated as nearly as possible; hence, only moderate applications of fertilizers were made.

YIELDS OF GRAIN FROM THE SELECTIONS.

The selections which produced the highest yields per acre in the 6-year test were 34a1-11-2 from the hybrid Sixty-Day $\times$ Burt, with an average yield of 61 bushels; selection 123-5 from the commercial variety Welcome, 60.5 bushels; selections 50a1-10 and 50a1-22 from the hybrid Sixty-Day $\times$ Probsteler, 60.4 and 58.2 bushels, respectively; and selection 62-II-18-1-1 from the commercial variety Sixty-Day, 57 bushels. Of the selections which exceeded 55 bushels in yield in the 6-year test, 4 were from series 34, Sixty-Day $\times$ Burt; 4 from series 49, Sixty-Day $\times$ Clydesdale; 2 from series 50, Sixty-Day $\times$ Prob-

steier; and 1 each from series 31, Burt×Red Rustproof; 62, Sixty-Day; 120, Silvermine; 123, Welcome; 125, Silvermine; and 5938, Sixty-Day.

In 1911 a comparatively small number of the selections was grown, but a large proportion of those which were dropped that year were again included in the tests in 1912. Of the selections which were grown in the five years, 1907, 1908, 1909, 1910, and 1912, 27 exceeded 55 bushels in average yield. Of these 27 selections, 10 were from series 49, 8 from series 34, 3 from series 50, and 1 each from series 31, 42, 62, 120, 123, and 5938.

COMPARISON OF SELECTIONS FROM HYBRIDS AND COMMERCIAL VARIETIES.

The average yield of all the selections from hybrids tested in 1907 was 50 bushels per acre, while the yield for all selections from commercial varieties was 49.4 bushels per acre. In 1908 the yield for all selections from hybrids was 55 bushels per acre, while that for all selections from commercial varieties was 49.3 bushels. In 1909 the average yields were 36.5 and 38.9 bushels, respectively; in 1910, 64.6 and 59.9 bushels; in 1911, 45.9 and 48.7 bushels; and in 1912, 52.5 and 51.1 bushels. The average for all the selections from hybrids tested for the years from 1907 to 1912, inclusive, was 51.3 bushels, while that for all selections from commercial varieties was 49.8 bushels. When the results are taken year by year it is seen that only in the years 1909 and 1911 were the yields of the selections from commercial varieties greater than the yields of the selections from hybrids.

The results, although indicating a higher yield for the selections from hybrids, do not show enough difference to warrant recommending hybridization over straight selection as a means of improvement. One advantage of the selections from commercial varieties is that it is possible to test a great many of them while one is purifying the hybrids from one cross. The purification of hybrids must be continued at least to the third generation before comparative tests can be made; meantime a great many selections could have been tested.

A somewhat different set of figures is obtained from the average yields of the different series as presented in Table IV. This table shows the annual and average yields of each series, without regard to the number of selections which were grown, for the years 1907, 1908, 1909, 1910, and 1912. The results for 1911 are not included, because several of the series were not grown that year. The averages for the selections from hybrids and from commercial varieties given in the summary are obtained from the yields of the different series, as shown in the table. For this reason they do not agree exactly with the averages in the preceding paragraph, where the individual selection, not the series, was the unit.

TABLE IV.—*Annual and average yields of the various series of oats grown at the Cornell University station in 1907, 1908, 1909, 1910, and 1912, with the 5-year average for each.*¹

Series No.	Parentage.	Yield (bushels per acre).					
		1907	1908	1909	1910	1912	Average.
SELECTIONS FROM HYBRIDS.							
3	Golden Giant×Asia Minor Rustproof.....	43.3	33.1	38.7	67.8	50.1	46.6
8	Danish Island×Asia Minor Rustproof.....	38.2	53.3	37.2	72.8	50.8	50.5
27	Garton Tartar King×Clydesdale.....	45.0	40.0	40.1	65.0	64.9	51.0
30	Burt×Clydesdale.....	56.2	49.3	36.2	65.0	50.8	51.5
31	Burt×Red Rustproof.....	42.4	78.7	42.3	65.6	45.8	55.0
32	Burt×Early Champion.....	42.5	62.5	42.8	64.7	47.2	52.0
33	Burt×Burt.....	37.4	62.4	33.1	79.7	55.0	53.5
34	Burt×Sixty-Day.....	44.7	66.3	36.7	65.9	44.5	51.6
38	Burt×Clydesdale.....	48.7	48.7	29.8	59.1	48.2	46.9
42	Asia Minor Rustproof×Clydesdale.....	45.9	60.0	36.2	62.3	55.0	51.9
49	Sixty-Day×Clydesdale.....	58.7	47.8	38.6	65.3	54.8	53.0
50	Sixty-Day×Probsteier.....	61.8	56.6	38.3	57.7	55.4	54.0
51	Sixty-Day×European Hull-less.....	51.2	37.5	29.6	51.2	48.6	43.6
Average.....		47.4	53.5	36.7	64.8	51.6	50.8
SELECTIONS FROM COMMERCIAL VARIETIES.							
62	Sixty-Day.....	57.7	62.8	41.9	56.9	48.3	53.5
63	Burt.....	44.7	57.5	39.9	65.2	47.3	50.9
115	Red Rustproof.....	42.5	30.0	36.3	53.4	62.6	44.9
117	Early Champion.....	51.2	18.7	29.6	47.1	41.9	37.7
118	Silvermine.....	51.2	47.5	39.9	51.4	82.8	54.6
120	do.....	57.5	42.5	48.3	62.7	67.3	55.7
123	Welcome.....	53.7	67.5	46.8	61.2	69.8	59.8
125	Silvermine.....	50.8	40.0	43.6	66.4	64.7	53.1
131	Pringle Progress.....	37.5	40.0	35.7	50.6	56.5	44.1
132	Sixty-Day.....	58.7	60.0	41.9	56.4	49.1	53.2
137	Early Champion.....	50.8	38.7	35.9	42.8	36.9	41.0
138	do.....	61.2	47.5	39.5	48.1	34.8	46.2
142	Goldmine.....	47.5	35.0	34.8	34.8	39.1	38.2
5938	Sixty-Day.....	60.0	55.0	56.9	57.5	55.2	56.9
Average.....		51.8	45.9	40.8	53.9	54.0	49.3
SUMMARY.							
Average of selections:							
From hybrids ²		47.4	53.5	36.7	64.8	51.6	50.8
From commercial varieties ²		51.8	45.9	40.8	53.9	54.0	49.3

¹ The results for 1911 are not included, as some of the series were not grown that year.² Averages based on the series as a unit.

Table IV gives some indication of the relative value at the Cornell station of the different hybrids and commercial varieties as stocks from which to make selections. The highest average yield for any series for the five years was that of series 31, Burt×Red Rustproof, 55 bushels, due largely to a very heavy yield in 1908. The next highest average yield, 54 bushels, was obtained from series 50, Sixty-Day×Probsteier, of which from 11 to 13 selections were grown each year, whereas only two selections from series 31 were grown. It is probable that series 50 is more valuable for New York than series 31; in fact, two selections from the former exceeded the best selections from the latter in average yield for the five years. Other valuable hybrid stocks, as indicated in Table IV, are series 33, Burt×Burt, and series 49, Sixty-Day×Clydesdale. Among the individual selections, some of the highest yielding ones are included in series 34,

Burt×Sixty-Day, but this series includes sufficient strains which are low in yield to bring its general average 2.4 bushels below that of series 50.

Of the commercial varieties, the highest averages for the five years are shown by series 123, Welcome, 59.8 bushels; 5938, Sixty-Day, 56.9 bushels; 120, Silvermine, 55.7 bushels; and 118, Silvermine, 54.6 bushels. Of the varieties included in this test it is probable that these three are the most valuable in the vicinity of the Cornell station.

PLACE VARIATION.

The variation in results and in the relative yields of the different strains from year to year has been considerable. This is well shown by the yields of the best 10 hybrids and selections for each year. In certain years the earlier strains represented by the Burt and Sixty-Day types are the best yielders, while in other years the later types represented by the Silvermine or Welcome yield best. This place variation operates to make 1-year varietal tests inconclusive. Unusual conditions affecting the results may arise in any season. For example, the growing seasons of 1909 and 1910 were both rather hot and dry at the time the oats were filling and ripening. Such conditions favor the Sixty-Day type, since it will withstand more hot, dry weather than the later sorts. The seasons of 1911 and 1912 were very different from those of 1909 and 1910. The early parts of these seasons were hot and dry, with the exception of early May, 1912. Most of the early-maturing selections ripened under adverse conditions, while the coming of rain and cooler weather gave an advantage to the later varieties. This is evidenced by the fact that the best yielding strains for 1909 and 1910 were early types, represented by the Sixty-Day series, while the best yielding strains for 1911 and 1912 were later types, represented by the Silvermine series.

COMPARISON OF THE BEST SELECTIONS WITH COMMERCIAL VARIETIES.

After the tests had been conducted for two years it seemed desirable to compare the yielding capacity of the different strains with some commercial varieties. A number of such varieties were brought into the test in 1909, but owing to lack of room only a few tests were made of each variety. More varieties have been added from time to time, so that at present most of the well-known commercial varieties are included. It was necessary to reduce the number of commercial varieties in 1911, but all of them were put back into the test for 1912.

Among the commercial varieties which were tested in 1909, 1910, and 1912, the highest average yield was obtained from the Lincoln variety, 65.1 bushels to the acre. This yield is 0.1 bushel higher than that of Welcome selection 123-5. In several larger tests conducted in different parts of the State during 1912, selection 123-5

outyielded the Lincoln variety. The two are very close together, however, and another year or two will possibly decide which one is better adapted to New York conditions.

When the average yield of the best eight selections for the three years is compared with the average yield of the eight unselected varieties, there is a marked difference in favor of the selections. The average yield of the eight selections is 61.5 bushels per acre, while that for the eight commercial varieties is 53.1 bushels per acre. The average for the eight new strains is higher than the yield of any one variety except the Lincoln. The average weight per bushel of the eight selections was 30.31 pounds, while that of the commercial varieties was 29.75 pounds.

TESTS AT VARIOUS OTHER EXPERIMENT STATIONS.

INTRODUCTION.

At various times from 1907 to 1910, seed of certain of the selections from hybrids and commercial varieties discussed in this bulletin was sent to a number of the State experiment stations. In addition to the data already reported from the Iowa and Cornell University stations, where the principal tests were conducted in cooperation with the Bureau of Plant Industry, valuable data have been obtained and are here reported from the Pennsylvania, Virginia, Ohio, Indiana, Kentucky, Tennessee, and Minnesota agricultural experiment stations. The results of tests at the Arlington Experimental Farm in Virginia are also included.

PENNSYLVANIA.¹

Twenty selections which were believed to be adapted to the local conditions were sent to the Pennsylvania experiment station in 1910. These strains were tested on a Hagerstown clay-loam soil in a good state of fertility. In 1910 and 1911 the oats followed potatoes in a rotation of potatoes, oats, wheat, and clover and timothy; in 1912 they were grown in a similar rotation in which corn replaced the potatoes. In each of the first two years 160 pounds of acid phosphate to the acre were applied to the oats; in 1912, 320 pounds were used. The 20 strains were grown in 1910 in rows 60 feet long and 14½ inches apart, made by sowing from alternate holes in the grain drill. In 1911 and 1912, owing to lack of land, only the most promising strains were grown. The plats were 139 by 5.5 feet in 1911 and 150 by 5.5 feet in 1912. The rate of seeding was 9 pecks to the acre.

The only strain which exceeded the check variety Japan in yield for the three years was a selection of the Sixty-Day, 62-II-18-1-1,

¹ These tests were made by Profs. F. D. Gardner and C. F. Noll, to whom acknowledgments are due for the results here reported.

with an average yield of 60.4 bushels to the acre, 5.32 bushels more than was obtained from the Japan. The average yield of straw for the years 1911 and 1912, however, was nearly 700 pounds to the acre less than that of Japan. As the straw is a valuable part of the crop in Pennsylvania, this difference is worthy of consideration. Selections 49a1-25-4 (Sixty-Day $\times$ Clydesdale) and 132-3-1 (Sixty-Day) averaged 53.63 and 53.26 bushels to the acre, respectively. In 1911 and 1912, several commercial varieties were grown in the same field with these selections. The highest yields obtained were 66.8 bushels from Joannette and 58.4 bushels from Sixty-Day, as compared with 59.3 bushels from the Sixty-Day selection 62-II-18-1-1.

VIRGINIA.

ARLINGTON EXPERIMENTAL FARM.

Spring oats are not ordinarily grown in the vicinity of Washington, D. C., where the Arlington Experimental Farm is located, as climatic and soil conditions usually make early spring planting difficult, and early planting is essential to the successful production of the crop. On the other hand, fall-sown oats of certain varieties generally survive the winter and produce good yields, maturing before the earliest spring-sown varieties. As it is sometimes desirable, however, to sow oats in this section in the spring, preliminary tests of more than 200 of the selections were made in 1908. The plantings were made on March 27 in rows 17 feet long and 1 foot apart. Only one row of each strain was grown. The season was rather unfavorable to spring oats, the highest yield being at the rate of 30 bushels to the acre. The following year, 1909, no spring oats were grown. In 1910, 16 of the strains which appeared to be most promising in 1908 were planted in 17-foot rows on March 22. In 1911 and 1912 these strains were planted in plats measuring 1 square rod each. The tests which have been conducted are altogether too meager to furnish data from which conclusions may be drawn. Apparently the most favorable strains are the selections of Sixty-Day, the hybrids of Burt and Sixty-Day (series 34), and selection 49a1-12 from the hybrid of Sixty-Day and Clydesdale. The latter has produced the highest average yield.

VIRGINIA AGRICULTURAL EXPERIMENT STATION.¹

In the spring of 1908, 47 strains of the hybrids and selections were sent to the Virginia experiment station at Blacksburg. The following year 46 additional strains were sent. The tests in 1908 and 1909 were made in rows 4 rods long and 1 foot apart, those of 1910 in

¹ These tests were made by Profs. Lyman Carrier and T. B. Hutcheson, to whom acknowledgments are due for the results here reported.

plats of 0.01 acre each and those of 1911 and 1912 in plats of 0.02 acre each. Figure 6 shows a portion of the nursery used in the 1908 test. Owing to lack of space, the number of strains under test was greatly reduced in 1911. Only those which appeared to be most promising, as indicated by the 1908 and 1910 tests,¹ were grown in the succeeding years.

Of the strains grown three or more years, the highest average yields to the acre were obtained from a pure line of the Sixty-Day oat, 62-II-6-3, 37.5 bushels; selection 34a1-32 from the hybrid Burt × Sixty-Day, 36.98 bushels; and a pure line of Silvermine, 125-3, 35.94 bushels. Of the commercial varieties grown at this station Silver-



FIG. 6.—A portion of the oat nursery at the Virginia experiment station in 1908.

mine leads in yield. None of the three strains just mentioned was included in the 1908 tests. Of the nine strains which have been grown all four years (1908 and 1910 to 1912), the highest average yield, 32.9 bushels, was produced by selection 33a1-4-1 from a hybrid of two strains of Burt, though this yield only slightly exceeded those of selections 34a1-19-4 and 34a1-25-2 from the hybrid Burt × Sixty-Day. Apparently, among the varieties tested the most promising for use in producing new strains for southwestern Virginia are the Silvermine, Sixty-Day, and Burt. Late-maturing selections in series 8, 42, and 45 did not compare favorably with the earlier ones in series 33 and 34.

¹ The 1909 crop was partially destroyed by a storm just before harvest, and for that reason the results for that year have not been used.

OHIO.¹

The tests at the Ohio Agricultural Experiment Station at Wooster have been quite extensive. Forty-seven of the selections were sent to Prof. C. G. Williams, agronomist, in 1908, and 62 were added to the tests the following year. These 109 selections represented the various series as follows: Series 8, 7 selections; series 27, 1; series 30, 5; series 31, 4; series 33, 8; series 34, 11; series 38, 1; series 42, 1; series 44, 1; series 48, 4; series 49, 27; series 50, 16; series 51, 3; series 62, 13; series 63, 3; series 132, 1; series 137, 2; and series 165, 1. The first test of these selections was made in duplicate in rows 17 feet long and 1 foot apart. Later tests of the more promising strains were made in hundredth-acre plats, a few of the best going finally into the regular varietal test in tenth-acre plats.

In 1908 four of the 10 highest yielding strains were of series 50, Sixty-Day $\times$ Probsteier, two were of series 49, Sixty-Day $\times$ Clydesdale, and two were of series 62, pure lines of Sixty-Day. The highest yield of all, however, 85.08 bushels to the acre, was obtained from 8c1-5-4, a selection from the hybrid Danish Island $\times$ Asia Minor Rustproof. Selections 50a1-24 and 50a1-15 from the hybrid Sixty-Day $\times$ Probsteier yielded 80.02 and 78.13 bushels, respectively. The highest yields obtained from pure lines developed at the Ohio station from three commercial varieties were as follows: Sixty-Day, 86.54 bushels; Siberian, 80.51 bushels; and Improved American, 81.2 bushels.

The highest acre yields produced by the selections from the Office of Cereal Investigations in 1909 were obtained from 50a1-15, 83.24 bushels; 50a1-21, 72.31 bushels; 50a1-24, 69.96 bushels; and 8c1-5-4, 69.96 bushels. The other six high-yielding strains from the 1908 tests yielded from 60 to 66 bushels each. The yield of 50a1-15, 83.24 bushels to the acre, was higher than that of any other variety tested in hundredth-acre plats in 1909.

In 1910 four strains from the Office of Cereal Investigations were grown in tenth-acre plats and 24 in hundredth-acre plats. The yields of the four strains in tenth-acre plats were as follows: 50a1-15, 63.64 bushels to the acre; 50a1-21, 56.25 bushels; 50a1-24, 74.11 bushels; and 8c1-5-4, 77.12 bushels. The only varieties from other sources which exceeded 8c1-5-4 in yield were Storm King, 79.3 bushels, and a selection from Siberian, 77.86 bushels. The average yields of the four strains just mentioned for the three years 1908, 1909, and 1910 were as follows: 8c1-5-4, 77.4 bushels; 50a1-15, 75 bushels; 50a1-24, 74.7 bushels; and 50a1-21, 67.6 bushels. Of the 24 strains grown in hundredth-acre plats in 1910 the best yields were produced by 34a1-11-2-1 and 34a1-11-2-3, 98.44 bushels to the acre each;

¹ These tests were made by Prof. C. G. Williams, to whom acknowledgments are due for the results here reported.

34a1-12-3, 88.28 bushels; 49a1-25-4, 87 bushels; 34a1-11-2-6, 86.72 bushels; 34a1-11-2-4, 85.94 bushels; and 34a1-12-1-1, 83.59 bushels.

The tests in 1911 and 1912 included only five of the strains, one of series 49 and four of series 34, the four strains which were grown on tenth-acre plats in 1910 having been lost. The highest average yields for the two years were produced by selections 34a1-11-2-3 and 34a1-11-2-6, 72.72 and 72.45 bushels to the acre, respectively, as compared with 75.38 bushels from a selection of Improved American made at the Ohio station and 75.18 bushels from a commercial lot of Silvermine. It is unfortunate that the strains of series 8 and 50, which were so promising in the earlier tests, were necessarily discontinued, as it is believed that they would have equaled or exceeded in yield those of series 34 and 49. From such evidence as is available the hybrids among those tested which appear to be of greatest value for Ohio are Danish Island $\times$ Asia Minor Rustproof, Burt $\times$ Sixty-Day, Sixty-Day $\times$ Clydesdale, and Sixty-Day $\times$ Probstieier.

INDIANA.¹

Fifty-five selections were sent to the Indiana experiment station for testing in 1909. As the quantity of seed sent was small, they were grown in short rows that year, and no record was taken of the yields obtained. The following year all were grown in plats of one one-hundred-and-thirty-second of an acre each. Because of lack of space 20 strains were discarded after the 1910 harvest and 14 more after the 1911 harvest. The 1911 and 1912 tests were made in plats of one-twentieth of an acre each. The highest average yield for the three years, 54.4 bushels to the acre, was produced by selection 34a1-11-2-1 from the hybrid Burt $\times$ Sixty-Day. This selection also produced the heaviest yield of straw. None of the other selections from this hybrid were high in yield. Selections 49a2-12, Sixty-Day $\times$ Clydesdale, and 50a1-20-7, Sixty-Day $\times$ Probstieier, ranked next in yield, with averages of 51.8 and 50.5 bushels, respectively. The highest yielding selection of Sixty-Day was 62-II-19-1, with an average of 48.6 bushels. Of the strains tested, those just mentioned appear to be most promising.

KENTUCKY.²

A lot of 33 oat selections was sent to Prof. W. H. Scherffius at the Kentucky experiment station by Mr. Norton in 1907. The following year 56 selections were added. These were all grown in 1908 and 1909. After the 1909 harvest the number of selections was reduced to 49 by the elimination of those that were low in yield in the tests

¹ The tests at the Indiana station were conducted by Prof. A. T. Wiancko, to whom acknowledgments are due for the results here reported.

² The writer is indebted to Profs. W. H. Scherffius, George Roberts, and E. J. Kinney for the data presented from the Kentucky station.

made up to that time. This number was further reduced to 30 after the 1910 test. All the tests were made in 17-foot rows.

The highest average yields for the five years from 1908 to 1912, inclusive, have been produced by selections 34a1-19-4 and 34a1-13-3 from the hybrid Burt $\times$ Sixty-Day, 54.4 and 52.1 bushels, respectively. Other high-yielding selections are 138-5 (Early Champion), 48.3 bushels; 34a1-25-3 (Burt $\times$ Sixty-Day), 46.6 bushels; 62-II-6-3 (Sixty-Day), 45.8 bushels; 34a1-11-3 (Burt $\times$ Sixty-Day), 45.7 bushels; and 34a1-25-2 and 34a1-27-4 (Burt $\times$ Sixty-Day), 45.6 bushels. Of the selections grown for six years the highest average yields have been produced by selection 138-5 (Early Champion), 46.3 bushels; 62-II-6-3 (Sixty-Day), 43.2 bushels; and 34a1-24 (Burt $\times$ Sixty-Day), 40.8 bushels.

In 1912 the six selections which produced the highest yields for the three years from 1908 to 1910 were grown in twentieth-acre plats in comparison with ordinary unselected Burt oats. The yields of these selections were as follows: 34a1-11-3, 60.6 bushels to the acre; 34a1-13-3, 56.6 bushels; 138-5, 55.4 bushels; 34a1-12-1, 54.1 bushels; 34a1-19-4, 53.4 bushels; 34a1-24, 53.1 bushels; and Burt, 44 bushels. From the yields obtained in these tests and in the nursery, it seems probable that some of the selections from the hybrid Burt $\times$ Sixty-Day and from the commercial varieties Early Champion and Sixty-Day will prove of value in Kentucky.

TENNESSEE.¹

Samples of seed of 112 selections were sent to the Tennessee experiment station in the spring of 1908. This lot was largely composed of selections from series 8 (Danish Island $\times$ Asia Minor Rustproof), series 33 (Burt $\times$ Burt), series 34 (Burt $\times$ Sixty-Day), and series 42 (Asia Minor Rustproof $\times$ Clydesdale). In 1908 these selections produced fairly good yields, but the following year and each year thereafter the spring-oat crop at the Tennessee station has either been destroyed by storms or so badly damaged as the result of them that no yields have been reported. Under date of October 19, 1912, Prof. C. A. Mooers writes:

We have had a rather unfortunate outcome to our trials of spring-oat selections. The last three years they have almost invariably been blown down and badly lodged before reaching maturity, which, of course, causes them to fill out poorly. We continued to discard those which were least promising, and this year we planted only the following, which seem to be closely related:

31a1-16-1-5.	34a1-11-2-3.	34a1-11-2-6.
34a1-11-1.	34a1-11-2-4.	34a1-13-5.
34a1-11-2-1.	34a1-11-2-5.	

¹The tests at the Tennessee station were made by Prof. C. A. Mooers, to whom acknowledgments are due for the results here reported.

MINNESOTA.¹

In the spring of 1908 fifty-three of the oat selections were sent to the Minnesota experiment station. These were tested in centgener beds from 1908 to 1911, inclusive. In the 1912 test the number of selections was reduced to 26 by the elimination of those that had made the least favorable showing in previous tests. The highest average yield per plant, perhaps the best indicator of the value of a strain grown in centgener tests, was obtained from selection 49a2-12 from the hybrid Sixty-Day $\times$ Clydesdale. The average yield per plant for this selection for the five years was 271.4 grams. Other selections from this hybrid which exceeded 250 grams in yield were 49a1-25-4 and 49a2-14-3. The only other selections which averaged as much as 250 grams of grain per plant were selections 50a1-3, 50a1-21, and 50a1-24 from the hybrid Sixty-Day $\times$ Probsteier. Some of the selections from the commercial variety Sixty-Day also yielded well.

SUMMARY.

The preliminary work in oat breeding was done at the Arlington Experimental Farm in Virginia and at McLean, Ill. A considerable number of hybrids were made in 1902, and numerous selections have been made from these and from commercial varieties in succeeding years.

The tests of these selections at McLean, which were continued until 1908, indicated the superiority of the Sixty-Day and Burt varieties and of hybrids between these varieties as material from which to select for central Illinois conditions. The selections from the hybrid Danish Island $\times$ Asia Minor Rustproof also produced high yields.

Sixty-four oat selections were tested at the Iowa experiment station for the six years from 1907 to 1912, and 381 selections for the four years from 1909 to 1912. These tests were made in duplicate in rows 15 feet long and 1 foot apart. The highest yields in the 6-year test were obtained from selections from the Welcome and Sixty-Day varieties and from the hybrid Sixty-Day $\times$ Probsteier. The highest yields in the 4-year test were obtained from selections from the hybrids Danish Island $\times$ Asia Minor Rustproof and Burt $\times$ Sixty-Day. The highest average yields for the various series of selections from hybrids and commercial varieties were obtained from the hybrids Golden Giant $\times$ Asia Minor Rustproof, Danish Island $\times$ Asia Minor Rustproof, and Burt $\times$ Sixty-Day, and from the commercial varieties Burt, Welcome, Silvermine, and Sixty-Day.

One hundred and forty-eight selections from hybrids and commercial varieties of oats have been tested in nursery rows at the Cornell University experiment station for one to six years. With the excep-

¹ The tests at the Minnesota station were made under the direction of Prof. A. Boss, to whom acknowledgments are due for the results here reported.

tion of one year, when the selections were grown on a gravelly loam soil, the tests have been conducted on a fairly fertile Dunkirk clay loam. The highest yields for the six years were obtained from selections from hybrids of Sixty-Day $\times$ Burt and Sixty-Day $\times$ Probstieier and from the commercial varieties Welcome and Silvermine. In general, the early-maturing strains produced larger yields than the medium or late maturing ones. The yields of selections from hybrids slightly exceeded the yields of selections from commercial varieties, but the difference is practically negligible. Eight selections produced an average yield 8.4 bushels to the acre higher than that of eight unselected commercial varieties in a 3-year test. The highest average yields, 65.1 and 65 bushels, were produced by the commercial variety Lincoln and the pure-line selection 123-5 from the Welcome variety, respectively.

None of the selections tested at the Pennsylvania experiment station appeared to be superior to the better commercial varieties. The best yielding selections were those from the Sixty-Day variety and from the hybrids Sixty-Day $\times$ Clydesdale and Burt $\times$ Sixty-Day.

At the Arlington Experimental Farm, selections from the Sixty-Day variety and from the hybrids Sixty-Day $\times$ Clydesdale and Burt $\times$ Sixty-Day have produced the highest yields.

At the Virginia experiment station, the highest yields have been obtained from selections from the Sixty-Day and Silvermine varieties and from the hybrid Burt $\times$ Sixty-Day.

Selections from the hybrids Sixty-Day $\times$ Probstieier, Danish Island $\times$ Asia Minor Rustproof, Burt $\times$ Sixty-Day, and Sixty-Day $\times$ Clydesdale have produced the largest yields at the Ohio experiment station. These yields have been slightly exceeded, however, by those of certain selections made at the Ohio station from commercial varieties.

The selections tested at the Indiana experiment station do not appear to be superior to the better commercial varieties which are grown there. The best yielding selection was one from the hybrid Burt $\times$ Sixty-Day.

At the Kentucky experiment station, selections from the commercial varieties Sixty-Day and Early Champion and from the hybrid Burt $\times$ Sixty-Day appear to be much better than unselected Burt or other commercial varieties which have been tested.

The tests at the Tennessee and Minnesota experiment stations do not supply sufficient data on which to base conclusions.





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(PROFESSIONAL PAPER.)

WALNUT APHIDES IN CALIFORNIA.

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INTRODUCTION.

The study of walnut aphides dealt with in the following pages was begun early in the year 1911 and continued until the summer of 1913. The observations were at first made at San Jose, Cal., but after September, 1912, the work was done chiefly at Walnut Creek, Cal. Practically all the life-history observations were made at the former locality, and much of the control work was done at Walnut Creek. The habits of the aphides do not vary materially throughout California. It was at first the writer's intention to confine his studies to the European walnut aphis (*Chromaphis juglandicola* Kalt.), as this species alone infests walnuts of commercial value grown in California, but latterly two native species of Aphididæ were found to be pests on native walnuts much used for stock on which to graft the European or Persian nut, and thus the studies were extended so as to include all three species. The two native aphides above mentioned are *Monellia caryæ* Monell, the American walnut aphis, which affects the eastern black walnut (*Juglans nigra*) and *Monellia caryella* Fitch, the little hickory aphis,¹ which affects the California black walnut (*Juglans californica*). Both of these species infest the Royal Hybrid walnut (a cross between the eastern black walnut and the California black walnut), while the Paradox Hybrid walnut (a cross between the European walnut and the California black walnut) is attacked by the European walnut aphis and to a lesser extent by the little hickory aphis. Both of these hybrids are rapid growers, and a certain percentage of the seedlings obtained from the crossings makes good stock on which to graft the commercial varieties of nuts. The great majority of European nuts and their varieties are grown in California

¹ This is the name Fitch gave to species which he found on hickory, and it seems best to retain it, although rather an unfortunate title in so far as California is concerned, as the only wild member of the Juglandaceæ in that State is *Juglans californica*.

on roots of either the California black walnut straight or on roots of one or the other of these two hybrids. When a graft has been made and both stock and scion are putting out leaves simultaneously, more than one species of aphid will usually occur on the same tree. In such a case the two species feed on their own particular host, but the migrant forms of either may be found resting on foliage of the opposite host. The Paradox and Royal hybrids are used in various parts of California as shade trees and will furnish a fine grade of wood, which will take on a high polish.

THE EUROPEAN WALNUT APHIS (*Chromaphis juglandicola* Kaltenbach).

Lachnus juglandicola Kaltenbach, Monographie der Familien der Pflanzenläuse, Aachen, 1843.

Callipterus juglandicola Koch, Die Pflanzenläuse Aphiden, Nürnberg, p. 224, 1857.

Callipterus juglandicola Passerini, Gli Afidi, Parma, 1860.

Callipterus juglandis Walker, The Zoologist, ser. 2, v. 5, p. 2000, Feb., 1870.

Pterocallis juglandicola Buckton, Monograph of the British Aphides, v. 3, London, 1881, p. 32-34.

Callipterus juglandicola Schouteden, Mem. Soc. Ent. Belg., v. 12, p. 209-210.

Chromaphis juglandicola Essig, Mo. Bul. Cal. State Com. Hort., v. 1, no. 5, p. 190-194, figs. 72-73, April, 1912.

In 1870 Walker erected the genus *Chromaphis* and designated *Callipterus juglandicola* Kaltenbach as the type species. Reference to this is made by H. F. Wilson in his paper "A Key to the Genera and Notes on the Synonymy of the Tribe Callipterini, Family Aphididae," Canad. Ent., v. 42, no. 8, p. 253-259, Aug., 1910.

HISTORY OF THE SPECIES.

The species was described originally by J. H. Kaltenbach in his "Monographie der Familien der Pflanzenläuse" as *Lachnus juglandicola*. A somewhat free translation of this description is as follows:

Wingless: Pale yellow, egg-shaped, flat, square, incised, and armed with glandular hairs on the margins; legs whitish-yellow, a black spot on the apex of the hind femora. Length, $\frac{1}{2}$ ".

Winged: Yellow; eyes red; antennæ whitish, with black rings; cornicles yellow, hardly noticeable; tail lacking.

This tree louse occurs sporadically in June and July in numbers under the leaves of the walnut tree (*Juglans regia*).

Wingless: Antennæ shorter than the head and thorax combined, not markedly jointed, whitish-yellow. Apex of antennæ black, of third joint ringed black. Eyes light red; beak short, scarcely reaching to the first coxæ. On the dorsum occur two longitudinal rows of black spots, which are absent on younger individuals. Cornicles and tail lacking. Legs hyaline whitish-yellow; a black spot is found on the upper side of the hind femora at their apices.

Winged: Antennæ noticeably shorter than the body, pale, the four major joints black at their apices; third joint distally enlarged; sixth joint with a gradually tapering thin apex. The body is yellow; in many cases the black dorsal spots of the abdomen are absent; in other cases but two to six are present; cornicles scarcely per-

ceptible, yellow; tail not present. Legs pale; the spots on the apex of the hind femora are larger than those of the wingless. In well-colored examples such spots occur on the middle femora and those on the hind femora are enlarged into a ring. The wings are transparent; the stigma yellow, cubitus and the two inner veins brown and markedly stouter at the base, then gradually becoming finer and paler; veins of lower wing and wing margin pale yellow; stigmatic or fourth vein very fine and strongly curved.

There is no doubt that Kaltenbach's species is the same that occurs commonly all over California on the European walnut. The black femoral spot, together with the antennæ as described, establishes its identity. Kaltenbach's wingless form appears to be the oviparous female in her penultimate molt, for the true apterous viviparous female—a common form in the majority of plant lice—does not exist, or, if it does, is extremely rare, the author in two years of close observation having failed to observe it. Buckton (1872)¹ gives a description of the apterous viviparous form, but he also seems to have had before him the immature oviparous form.

The insect probably occurs wherever the European walnut is grown. It has been reported from all over Europe, as well as from the States of Colorado (Gillette, 1910), Oregon (Wilson and Lovett, 1911-12), and California (Essig, 1909).

GENERAL DESCRIPTION; CHARACTER AND EXTENT OF INJURY.

This aphidid is a small, lemon-yellow insect, about one-sixteenth of an inch in length. It occurs sporadically on the underside of the leaves and on the young fruit of the European walnut (*Juglans regia*) and its cultivated forms and hybrids. It appears on the upper surface of the leaf only at times of very severe infestation. It is to be found from late February or early March until December, persisting as long as the leaves remain on the tree, but is present in greatest numbers during the months of July and August. As many as 200 individuals may occur on a single large leaflet if infestation be severe, while the author has observed over 30 aphides on a single young nut. Nuts badly infested while young never attain their normal size. Many of them mature half-sized, covered on the upper surface with the black sooty fungus which thrives on the sticky exudations of the aphides. Attacks on the tree year by year also materially reduce its vitality, since the aphides will be present in the spring even before the leaves have opened and will remain until these drop.

Plate I, figure 1, shows the difference in size between infested and uninfested nuts of one variety of European walnut, while Plate I, figure 2, demonstrates the appearance of the sooty fungus on a walnut leaf.

¹ Dates in parentheses refer to the Bibliography, p. 47.

LIFE HISTORY AND TECHNICAL DESCRIPTIONS.

THE VIVIPAROUS OR ASEXUAL FORMS.

When the young stem-mother is ready to emerge in the spring she causes the shell of the winter egg to burst with a longitudinal slit on the dorsal surface from the micropylar end. (See fig. 1.) Egress is performed head first, and antennæ and legs are requisitioned by the young larva in worming its way out of the shell. While the process of emerging, which occupies half an hour or more, is taking place, the aphid assumes an erect position at right angles to the long axis of the egg. After the exit of the young the eggshell has a large triangular hole at the micropylar end.

As soon as the buds begin to swell in early spring these stem-mothers hatch and continue hatching until the leaves have fully opened out, at which time all will have issued from the egg. The earliest plant-lice to emerge may be seen wandering over the bare twigs and buds, apparently feeding a little upon the scales protecting the unopened buds, but not showing much growth until the buds have opened and can afford nourishment.



FIG. 1.—*Chromaphis juglandicola*: Group of eggs, three lowest hatched. Twenty times natural size. (Original.)

Undoubtedly many of the aphides that hatch early die of ill nourishment, and some of these do not attain their full development for six or seven weeks, while those hatching later and finding tender food in abundance become full grown at the end of five weeks. Certain it is that on a particular tree the stem-mothers all became winged almost simultaneously. On trees which leaf early the stem-mothers will begin emerging from the egg as early as February 15, but on the Franquette and such late varieties no aphides will be found until in April. Immediately after hatching the lice seek the buds or young leaves. In the former case the aphides crawl in between the scales, but on the leaves they appear on the lower or exposed side, notwithstanding the fact that much better protection is afforded by the upper, as yet unfolded, surface which at that time is almost entirely hidden from view. Possibly the sticky character of the upper surface of the leaves repels them. Table I indicates the life cycle of four stem-mothers which hatched after the buds had opened.

TABLE I.—Period of development of the stem-mother of *Chromaphis juglandicola*, San Jose, Cal., 1912.

No. of individual.	Date of hatching.	Date of acquiring wings.	Period from hatching to maturity.
1.....	Mar. 24	Apr. 28	Days.
2.....	24	28	35
3.....	24	28	35
4.....	24	29	36
Average period.	.....	.....	35.25



FIG. 1.—THREE MATURED NUTS OF EUROPEAN WALNUT SEEDLING.
[Middle nut natural size, other two undersized from attack by aphides.]



FIG. 2.—UPPER SIDE OF THREE LEAFLETS OF EUROPEAN WALNUT SEEDLING.
[The central leaflet shows growth of fungus thriving upon the exudation of aphides above.
Two-thirds natural size.]

THE STEM-MOTHER; NEWLY HATCHED YOUNG (FIG. 2).

Oval, lemon yellow. Eyes red, of moderate size. Antennæ 3-jointed, not quite reaching to base of second coxæ; joint III nearly three times as long as joints I and II together. Legs comparatively long, entirely pale. Body covered with capitate hairs. Cornicles very small, pale whitish-yellow, hardly raised above the surface of the body. Cauda small, pale, bluntly conical. Beak entirely pale, reaching second coxæ. Black knee spots characteristic of this species absent. Measurements: Length of body, 0.72 mm.; width, 0.30 mm.; antenna, joint I, 0.04 mm.; joint II, 0.035 mm.; joint III, 0.145 mm. Almost immediately after birth the legs and antennæ turn dusky gray and the dark abdominal spots appear. In this respect the young of the stem-mothers differ from those of all other generations, for the appendages of the young aphides of subsequent broods never turn entirely dusky nor do the abdominal spots appear so early.

THE STEM-MOTHER; 4 DAYS OLD.

Yellowish-green, flatly oval, closely appressed to the surface of the leaflet or bud scale. Antennæ and legs dusky gray. Eyes circular, red, small. Head, thorax, two proximal antennal joints, and abdomen bearing capitate hairs which arise (those of the antennæ excepted) from small tubercles situated in the middle of a small, circular, dusky area. Antennæ 3-jointed, the distal joint the largest. Cornicles very small, erect. Cauda almost as long as the hind tarsus, its apex blunt. Cornicles and cauda concolorous with the abdomen. Beak very pale, reaching second coxæ, its extreme apex brown. Under-side of the head very pale yellow; of the abdomen greenish-yellow.

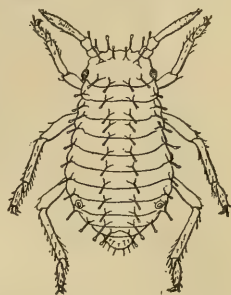


FIG. 2.—*Chromaphis juglandicola*: Stem-mother, newly hatched. (Original.)

THE STEM-MOTHER; AFTER FIRST MOLT AND JUST PREVIOUS TO SECOND MOLT.

Pale lemon-yellow or yellowish green, flatly oval, closely appressed to the plant surface, occurring on the underside of the expanding leaves, between the ribs. Antennæ and legs very pale yellow, almost hyaline. Antennæ short, reaching slightly beyond the posterior margin of the prothorax, 3-jointed, with a rudimentary suture on the distal half of joint III. This joint is about three times as long as the two proximal joints together. Eyes crimson, not fully developed. Legs entirely pale, without any trace of dark knee spots. Thorax and segments 1 to 6 of the abdomen with two longitudinal rows of black or brown spots, on each of which occurs a small pale tubercle bearing two capitate hairs, one larger than the other. On the thoracic segments and on abdominal segments 1 to 7 occur two rows of pale lateral tubercles, each of which bears three capitate hairs. The frontal margin of the head bears six such hairs on tubercles. Antennal joints I and II with a capitate hair on their inner margins near the middle, and joint III with one such hair on the inner margin near the base. The eighth abdominal segment bears a dorsal fringe of six capitate hairs, those on either end being smaller than the four inner ones. Cornicles situated on segment 6, as broad as long, erect, concolorous with the abdomen. Cauda without armature, bluntly conical, almost hyaline, about as long as the hind tarsus. Beak barely reaching second coxæ, pale yellow, the extreme tip brown. Measurements: Length of body, 1.55 mm.; width, 0.775 mm.; antenna, joint I, 0.053 mm.; joint II, 0.048 mm.; joint III, 0.304 mm.

Described from specimens collected at San Jose, Cal., March 28, 1912.

After the second molt the spines on the dorsum of the body disappear. (See fig. 3.)

The pupal and imaginal stages of the stem-mother show no apparent difference in respect to size, color, or structure from those of the later viviparous generations, and thus one description of these forms will suffice for all the winged viviparous generations.

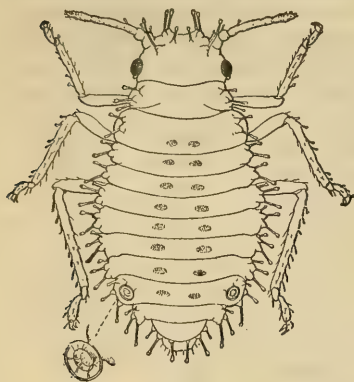


FIG. 3.—*Chromaphis juglandicola*: Larva of stem-mother after second molt. (Original.)

spots on the dorsum, which spots are always present on segment 5 but often lacking on the other segments. Head, thorax, and abdomen furnished with lateral rows of capitate hairs which stand on small pale tubercles. Cornicles small, as wide as long, slightly constricted in the middle, situated on the sixth abdominal segment. Cauda short, about as long as the cornicles, bluntly rounded at the apex. Cornicles and cauda concolorous with the body. Beak short, pale, stout, reaching to the first pair of coxæ. The pupa has the legs relatively a little shorter than those of the adult and is thus more closely appressed to the leaf surface. The body is quite flat. Measurements: Length of body, 1.87 mm. (average); width, 0.85 mm. (average maximum); antenna, joint I, 0.050 mm.; joint II, 0.042 mm.; joint III, 0.183 mm.; joint IV, 0.081 mm.; joint V, 0.076 mm.; joint VI, 0.065 mm.; filament, 0.034 mm. Cornicles, 0.04 mm.

The stem-mothers pass through the pupal molt about one week before the final molt takes place, and after the latter they acquire their full development as winged adults. In the latter generations the pupal instar occupies from three to six days.

THE WINGED VIVIPAROUS FEMALE (FIG. 5).

General color pale lemon-yellow; many individuals are darker yellow, yellowish-brown, or salmon-pink. Antennæ on very small frontal tubercles, about one-half the length of the body, yellow, with the inner lateral margins of the first two joints dusky; articulations of joints III to VI and the whole filament dusky to black. Eyes red. Ocelli present. Prothorax yellow. Thoracic lobes and scutellum light brown, sometimes greenish-yellow, pale yellow in newly-molted individuals. Wings of medium

THE PUPA OF THE WINGED VIVIPAROUS FEMALE (FIG. 4).

General color pale lemon-yellow. Eyes red, fully formed. Antennæ reaching a little beyond the base of the wing-pads, pale, joint III the longest, joints IV and V subequal. Ocelli present. Anterior margin of the head bearing six capitate spines. Thoracic segments pale yellow. Wing-pads pale yellow, closely appressed to the sides of the body. Legs pale yellow, with the dark knee spot on the hind femora only; tarsi dusky. Abdomen oval, pale lemon-yellow, with a varying number of dark

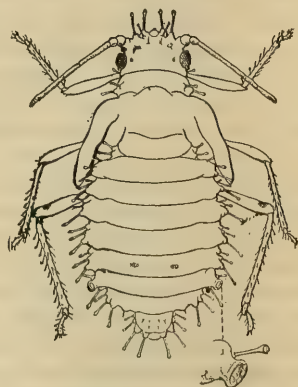


FIG. 4.—*Chromaphis juglandicola*: Pupa of winged viviparous female. (Original.)

size; subcosta and wing insertions pale yellow; stigma pale gray, with a darker area at the confluence of the third discoidal vein, and another such though smaller area at the apex; veins rather heavy, dark brown, all three discoidals arising from the subcosta and thickened at their bases; second branch of third discoidal nearer the wing apex than the first fork; third discoidal describing a regular gentle curve for its entire length; stigmatic vein entire, the depth of its curve varying in different examples, generally reaching the wing margin midway between the apex of the stigma and the end of the third discoidal (often it touches the margin considerably nearer the stigma, but rarely nearer the third discoidal). Legs rather short, but a little longer than those of the pupa; front pair yellow with the tarsi and apical third of the tibiae dusky



FIG. 5.—*Chromaphis juglandicola*: Winged viviparous female (appendages of left side removed). *a*, Left antenna; *b*, right cornicle; *c*, front tarsus. (Original.)

gray and the knee spot rarely present (gray when present); middle pair yellow, with an indefinite gray spot on the upper side of the femur above the knee and with the tarsi dusky gray; hind pair yellow, with a coal-black spot (sometimes produced into an annulation) on the upper side of the femur above the knee joint and with the tarsi dusky gray as in the other pairs. The knee spots are always present on the hind femora, while they occur in about 80 per cent of individuals on the middle femora. In 35 individuals examined throughout the year all had the spots on the hind femora, 28 had spots on the middle femora, and only 1 had spots on the fore femora. Abdomen pale lemon-yellow, widest at segment 3, considerably wider than the thorax, generally bearing two oval brown spots on segment 5 and more rarely with two similar but smaller spots on segment 4; occasionally immaculate. These spots are sometimes grayish, varying in intensity, and appear to be the pupal markings retained in the adult form.

Cornicles (fig. 5, *b*) pale yellow, constricted in the middle, barely as long as broad. Abdominal segments 3 to 6 inclusive bearing pale lateral tubercles. Body without hairs. Cauda very pale, globular, about as long as the cornicles. Beak pale yellow, the extreme tip black, reaching a little beyond the first coxæ. Sternum pale brown. Measurements: Length of body, 1.62–2.55 mm., average 2.08 mm.; width of body at segment 3 of abdomen, 0.71–1.06 mm., average 0.88 mm.; wing expanse, 4.42–5.21 mm., average 4.77 mm.; antenna, joint I, 0.046–0.067 mm., average 0.055 mm.; joint II, 0.039–0.055 mm., average 0.043 mm.; joint III, 0.267–0.408 mm., average 0.337 mm.; joint IV, 0.153–0.233 mm., average 0.196 mm.; joint V, 0.133–0.191 mm., average 0.162 mm.; joint VI, 0.079–0.094 mm., average 0.083 mm.; antennal filament, 0.038–0.043 mm., average 0.040 mm.; total length of antenna, 0.775–1.060 mm., average 0.916 mm.; cornicles, 0.05 mm.; cauda, 0.056 mm.

There are from 6 to 8 transverse oval sensoria on antennal joint III, 1 terminal sensorium on joint V, and three terminal ones on joint VI. Buckton's measurements (Buckton, 1872) seem to have been taken from small examples for, with the exception of those of the antennal joints, his measurements are all smaller than the average found by the writer. It may be that California examples are larger than the European.

Within a few hours after the last molt the wings harden and the chitin stiffens. The stem-mothers then begin to deposit the young that have been visible as pseudova for a week or longer inside their bodies. In the life-history experiments the greatest number of young produced by one viviparous female was 44. These were extruded from the body in 20 days, 30 in the first half and 14 in the last half of that period. Several adults under observation deposited 11 or 12 young within 12 hours after reaching maturity, and no more after that, dying with many unborn pseudova in their bodies. In the field the aphides deposit all their young on one leaf or on several leaves near one another. The average number of young deposited by a single adult ranges between 25 and 35. This seems to be about the same as in other closely related Callipterini, but is a much smaller number than that occurring in members of other tribes of Aphididæ. The aphides of the fall viviparous generation produce fewer young, those which develop in November depositing only 6 or 8. As many as 30 oval unborn aphides may be seen in the body of one recently molted female. These embryos vary in size, only those to be deposited immediately being fully grown. Each is inclosed in a very thin hyaline sac in which they are contained at birth.

The newly deposited young of the second and subsequent generations, both viviparous and oviparous, differ from the infant stem-mothers in that they are entirely pale yellow (rarely suffused with a faint pink) and remain thus until the first molt, while the young stem-mothers have dusky appendages and abdominal spots. The young deposited by the stem-mothers pass through their first molt in from three to six days. After this molt there appear brown or black dorsal spots in the majority of the individuals, and these markings persist through the succeeding molts. A small percentage

of examples remain immaculate throughout development. The "lice" of the second generation develop more quickly than the stem-mothers or first generation, owing to greater abundance of food supply and to the higher temperature existing at that later period. In 1911 second-generation young were deposited in the field on early varieties of walnuts a little before April 23, while in the following year these were deposited as early as April 6. This is to be expected, since in 1912 the trees came out in leaf two weeks earlier than in the previous year. Table II shows the life cycle of 41 individuals of the second generation at San Jose, Cal., in 1911.

TABLE II.—*Life cycle of the second generation of Chromaphis juglandicola, San Jose, Cal., 1911.*

No. of individual.	Date of—		Life cycle.	No. of individual.	Date of—		Life cycle.
	Deposition.	Acquiring wings.			Deposition.	Acquiring wings.	
			<i>Days.</i>				<i>Days.</i>
1.....	Apr. 23	May 12	19	22.....	May 2	May 22	20
2.....	23	12	19	23.....	2	22	20
3.....	23	14	21	24.....	3	22	19
4.....	23	16	23	25.....	3	22	19
5.....	23	18	25	26.....	3	22	19
6.....	24	18	24	27.....	3	22	19
7.....	24	18	24	28.....	3	22	19
8.....	24	18	24	29.....	4	23	19
9.....	24	18	24	30.....	4	23	19
10.....	24	18	24	31.....	5	25	20
11.....	25	20	25	32.....	5	25	20
12.....	26	21	25	33.....	5	25	20
13.....	May 1	21	20	34.....	6	26	20
14.....	1	21	20	35.....	6	26	20
15.....	1	21	20	36.....	6	27	21
16.....	1	21	20	37.....	6	27	21
17.....	1	21	20	38.....	6	27	21
18.....	2	21	19	39.....	7	27	20
19.....	2	21	19	40.....	8	28	20
20.....	2	22	20	41.....	9	27	18
21.....	2	22	20				

Life cycle:	Days.
Maximum.....	25
Minimum.....	18
Average.....	20.7

The aphides of the third generation appear on the earliest varieties of walnuts about the middle of May, but on the late varieties such as the Franquette this brood appears as much as a month later. The individuals of this generation are on the average slightly larger than those of other generations. In a large series of adult viviparous females taken throughout the year of 1911 the largest example was of the third generation. Its body was 2.55 mm. in length and 1.06 mm. in width, and both of its antennæ measured 1.06 mm., or 0.02 mm. in excess of the next longest antenna in the series. Table III indicates the life cycle of 97 individuals of the third generation.

TABLE III.—*Life cycle of the third generation of Chromaphis juglandicola, San Jose, Cal., 1911.*

No. of individual.	Date of—		Life cycle.	No. of individual.	Date of—		Life cycle.
	Deposition.	Acquiring wings.			Deposition.	Acquiring wings.	
			<i>Days.</i>				<i>Days.</i>
1.....	May 19	June 4	16	50.....	May 19	June 7	19
2.....	19	4	16	51.....	19	7	19
3.....	19	4	16	52.....	19	7	19
4.....	19	4	16	53.....	19	7	19
5.....	19	5	17	54.....	19	7	19
6.....	19	5	17	55.....	19	7	19
7.....	19	5	17	56.....	19	7	19
8.....	19	5	17	57.....	19	8	20
9.....	19	5	17	58.....	19	8	20
10.....	19	5	17	59.....	19	8	20
11.....	19	5	17	60.....	19	8	20
12.....	19	5	17	61.....	19	8	20
13.....	19	5	17	62.....	19	8	20
14.....	19	5	17	63.....	19	8	20
15.....	19	5	17	64.....	19	9	20
16.....	19	5	17	65.....	19	9	21
17.....	19	5	17	66.....	19	10	19
18.....	19	6	18	67.....	22	11	20
19.....	19	6	18	68.....	22	11	20
20.....	19	6	18	69.....	22	11	20
21.....	19	6	18	70.....	22	11	20
22.....	19	6	18	71.....	22	11	20
23.....	19	6	18	72.....	22	11	20
24.....	19	6	18	73.....	22	11	20
25.....	19	6	18	74.....	22	11	20
26.....	19	6	18	75.....	22	11	20
27.....	19	6	18	76.....	22	11	20
28.....	19	6	18	77.....	22	11	20
29.....	19	6	18	78.....	22	11	20
30.....	19	6	18	79.....	22	11	20
31.....	19	6	18	80.....	22	11	20
32.....	19	6	18	81.....	22	11	20
33.....	19	6	18	82.....	22	11	20
34.....	19	6	18	83.....	22	11	20
35.....	19	6	18	84.....	22	12	21
36.....	19	6	18	85.....	22	12	21
37.....	19	6	18	86.....	22	12	21
38.....	19	6	18	87.....	22	12	21
39.....	19	6	18	88.....	22	12	21
40.....	19	6	18	89.....	22	12	21
41.....	19	6	18	90.....	22	13	22
42.....	19	6	18	91.....	22	13	22
43.....	19	7	19	92.....	22	13	22
44.....	19	7	19	93.....	22	14	23
45.....	19	7	19	94.....	22	14	23
46.....	19	7	19	95.....	22	14	23
47.....	19	7	19	96.....	22	15	24
48.....	19	7	19	97.....	22	15	24
49.....	19	7	19				

Life cycle:	Days.
Maximum.....	24
Minimum.....	16
Average.....	19.1

Generations IV to VIII inclusive occupy roughly 16 days apiece for development, and this period is the average life cycle during the summer months. Some aphides will develop in 14 days and others in 19 or 20. Table IV gives the life-cycle records of these five generations and also that of the ninth. The records in some instances are small, but the fact that in the first five of these generations there is practically no difference in the duration of the life cycle was corroborated by a larger series of experiments during the summer months with individuals of which the respective generations were unknown.

TABLE IV.—Life cycle of the summer generations of *Chromaphis juglandicola*, San Jose, Cal., 1911.

Generation No.	No. individual.	Date of—		Life cycle.	Form of individual.
		Deposition.	Reaching adult state.		
IV.....	1	June 8	June 28	Days. 20	Viviparous.
	2	16	July 1	15	Do.
	3	16	1	15	Do.
	4	16	1	15	Do.
	5	16	2	16	Do.
	6	16	2	16	Do.
	7	16	2	16	Do.
V.....	1	July 1	15	14	Do.
	2	1	15	14	Do.
	3	1	17	16	Do.
	4	1	18	17	Do.
	1	15	31	16	Do.
	2	15	31	16	Do.
	3	15	31	16	Do.
VI.....	4	15	31	16	Do.
	5	15	31	16	Do.
	6	15	31	16	Do.
	7	15	31	16	Do.
	8	16	Aug. 1	16	Do.
	9	16	1	16	Do.
	10	16	1	16	Do.
	11	16	2	17	Do.
	12	16	2	17	Do.
	13	16	2	17	Do.
	14	16	2	17	Do.
	15	17	2	16	Do.
	16	17	2	16	Do.
	17	17	2	16	Do.
	18	17	3	17	Do.
VII.....	19	17	4	18	Do.
	20	18	5	18	Do.
	21	18	6	19	Do.
	22	18	6	19	Do.
	1	Aug. 2	17	15	Do.
	2	2	17	15	Do.
	3	2	17	15	Do.
	4	2	19	17	Do.
	5	3	20	17	Do.
	6	3	20	17	Do.
VIII.....	7	3	20	17	Do.
	1	18	Sept. 1	14	Do.
	2	19	2	14	Oviparous.
	3	19	2	14	Do.
	4	19	3	15	Do.
	5	19	3	15	Do.
	6	19	3	15	Do.
	7	19	3	15	Do.
	8	19	3	15	Do.
	9	19	3	15	Do.
	10	20	4	15	Do.
	11	20	4	15	Do.
	12	20	4	15	Do.
	13	20	6	17	Viviparous.
	14	20	6	17	Oviparous.
IX.....	15	20	6	17	Do.
	16	20	7	18	Viviparous.
	1	Sept. 5	30	25	Oviparous.
	2	5	Oct. 1	26	Do.
	3	5	6	31	Viviparous.
	4	5	6	31	Do.
	5	5	8	33	Do.
	6	5	8	33	Do.
	7	7	9	32	Do.
	8	7	11	34	Do.
	9	7	13	36	Do.
	10	7	14	37	Do.
	11	7	14	37	Do.
	12	8	12	34	Do.
	13	8	17	39	Do.
	14	8	17	39	Do.

An inspection of Table IV shows that the length of the life cycle of Generations IV to VII was almost the same. This is to be expected, since in 1911 the months of June, July, and August had almost identical temperatures both day and night. It will also be observed that there was a very noticeable difference between the life-cycle periods of Generations VIII and IX, 16 individuals of the eighth generation averaging 15.4 days and 14 individuals of the ninth generation averaging 33.4 days. The ninth generation thus required for development a period over twice as long as that required by the preceding generation, developing almost as slowly as the stem mother generation (see Table I). Yet the temperature during the daytime influencing the ninth generation differed but little from those which obtained during the development of the eighth. The probable causes of the slow development of the ninth generation lice is to be found in the colder night temperatures to which they were subjected and in the fact that the leaves at this time are becoming less vigorous and consequently afford poorer nourishment for the aphides than earlier in the season. There is a tenth generation, and in warm early seasons probably an eleventh, but in these generations the brood is small and the "lice" grow slowly. Plant lice may be found in early December giving birth to young, which are destined to perish either when the leaves drop or through exposure to hard frost. The author has observed dead aphides of all sizes on the brown frosted leaves during early winter.

All the plant lice used for the life-history experiments were reared out of doors on young seedling walnut trees planted in pots and inclosed with glass cylinders. In 1911 the stock was procured from stem mothers collected on the earliest varieties of walnuts. When the work was started in 1911 it was too late to procure eggs, and so the data on the stem-mother cycle was acquired in 1912.

After the ninth generation no more life-history experiments were carried on in the rearing cages, but a weekly examination was made of infested leaves in the field to determine the proportions of the different forms, sexual and asexual, during the fall months.

THE OVIPAROUS OR SEXUAL FORMS.

The oviparous forms are the true sexes, comprising the winged male and the wingless oviparous, or egg-producing, female. The female aphis, after fertilization by the male, deposits true eggs, in which form alone the insect can tide over the winter months when no food supply is procurable.

As is shown in Table IV, there is no real oviparous generation, for in all the later or fall generations a certain percentage of the young will develop either into the sexed males or the sexed females. On heavily infested trees oviparous aphides appear as early in the season

as July, while on trees attacked by few lice these forms will not occur until September or October. It therefore seems that the more heavily a tree is infested the earlier will the sexed forms be produced.

A glance at Table IV demonstrates that the first oviparous form of the life-cycle material became adult September 2, and was a member of the eighth generation. In the field the first oviparous form was observed in 1911 on July 7, and in 1912 on July 9. Both of these occurred on early-leaving trees and probably belonged to the fifth or sixth generation. As the growth of the aphid colony may be said to have reached its zenith about the middle of July, it is at the time of its greatest abundance that the sexed individuals begin to appear. And, indeed, for the welfare of the species they appear none too soon, for it is in July and August that the hordes of natural enemies work tremendous havoc, frequently cleaning up a bad infestation on a tree within three weeks. Those sexual females that have gone to the trunk and limbs to deposit their eggs very often escape destruction while the others remaining on the foliage are devoured. Until the middle of August the sexual forms are comparatively rare and comprise less than 5 per cent of the whole, but after that time they become more and more abundant. The sexed females always greatly outnumber the males. Table V indicates the advance and decline of the sexual forms in the late summer and fall. The data were obtained by weekly visits to badly infested trees, during which the lice on a certain number (50) of leaflets picked out at random were counted. It must be borne in mind that as the fall advances more and more sexual females repair to the limbs for the purpose of depositing their eggs, and that therefore in the case of the later counts a really greater proportion of these were present on the trees than would appear from the records.

TABLE V.—*Comparative numbers of sexual and asexual forms of Chromaphis juglandicola observed on the foliage at different dates, San Jose, Cal., 1911.*

Date of collection.	Number of—			Percent- age of—
	Vivipa- rous forms.	Ovipa- rous forms.	Males.	Vivipa- rous forms.
September 15.....	241	247	4	49
23.....	258	355	5	42
30.....	203	143	6	58
October 7.....	171	66	9	70
14.....	166	74	14	65
24.....	207	117	9	62
November 2.....	172	111	4	60
9.....	420	80	11	82
16.....	233	36	7	84
23.....	10	0	0	100
Total.....	2,081	1,229	69	
Average.....				61.6

The maximum number of aphides found on a single leaflet throughout the counts was 90, of which 64 were sexual females. This occurred on the first date of collection.

It will be noticed from Table V that on the first two dates the oviparous forms were predominant but that on all later dates these were outnumbered by the viviparous individuals. On the date of the fourth collection (October 7) numerous sexual females were found on the limbs of the tree, and their number was more and more augmented each succeeding week. About October 1 the males appeared in numbers, very few of them having been in evidence previous to this time, although the first male of the season was noticed July 10. Table VI indicates the preponderance in numbers of the sexual female over the male.

TABLE VI.—*Preponderance of the sexual female of Chromaphis juglandicola over the male.*

Date of collection or count.	Number of sexual females to each male.	Date of collection or count.	Number of sexual females to each male.
September 15.....	62	October 24.....	13
23.....	71	November 2.....	28
30.....	24	9.....	7
October 7.....	7.3	16.....	5
14.....	5.3	23.....	(¹)

¹ None of either sex seen on leaves.

Table VI was compiled from the same material as that used for Table V. On November 9 nearly all the sexual females were clustered on the limbs, and two weeks later they and all other plant lice at the experimental trees succumbed to a severe frost, which had at the same time withered all the leaves. This clustering of the sexual females or sexuparæ about the limbs explains the small percentage of this form as compared with the males on November 9 and 16.

Copulation seems to occur only on the leaf, and the females are not fertilized until they have passed through the last molt. A single male may fertilize several females—probably quite a large number when it is considered that the latter sex so greatly outnumbers the former and that very few eggs prove infertile. Copulation in all instances observed by the writer occupied some 30 seconds of time—a very short period for an aphid. If the male be disturbed, he will immediately retract his genital organ and move off. In 1912 the males appeared in comparative abundance in the vicinity of San Jose as early as August 26.

In general appearance the adult oviparous female differs from the viviparous form in that it is wingless, has a wider body, and bears three conspicuous transverse brown or black bands on the dorsum of the abdomen. The male is greenish-yellow, winged, with black

or dusky gray legs and antennæ. The oviparous or sexual female molts four times but does not differ in appearance from the viviparous form until the third molt is passed.

THE OVIPAROUS FEMALE, AFTER THE THIRD MOLT (FIG. 6).

Rather smaller and narrower than the full-grown form. General color pale gamboge-yellow, sometimes lemon yellow. Body twice as long as wide. Eyes bright red. Head with six erect, capitate spines on the anterior margin. Antennæ short, reaching barely to the middle of the mesothorax; 7-jointed, joint III the longest, joints IV and V subequal, joint VI longer than its spur or filament. Spur dusky, rest of antennæ pale lemon yellow. Head, thorax, and abdomen with two longitudinal rows of oval black spots on the dorsum. Thorax and abdominal segments 1-5 with two lateral longitudinal rows of circular black spots, on which are situated small tubercles bearing capitate hairs. Such tubercles also occur on the black dorsal spots. Eighth segment of the abdomen unmarked, bearing on its posterior margin a fringe of six capitate hairs. Legs pale greenish-yellow with the characteristic knee spot on the hind femora only; tarsi gray. Cornicles on the sixth segment, quite small, wider than long, pale lemon-yellow. Cauda equal in length to the hind tarsus, pale yellow, rounded. Beak very pale, almost white, reaching to the anterior coxæ. Measurements: Length of

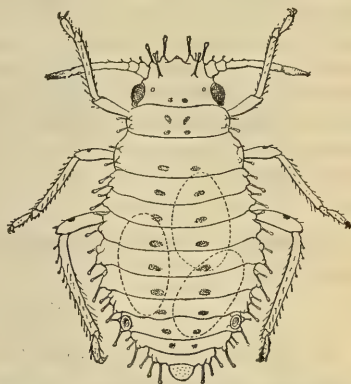


FIG. 6.—*Chromaphis juglandicola*: Oviparous female, penultimate instar. (Original.)

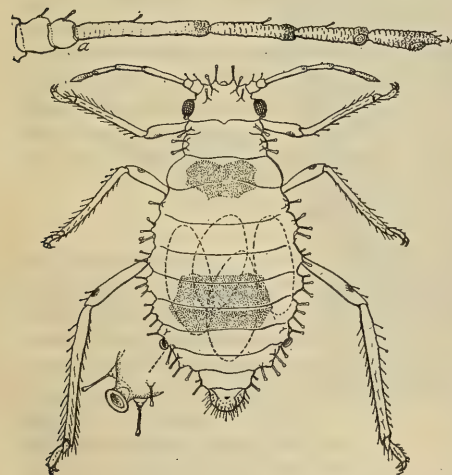


FIG. 7.—*Chromaphis juglandicola*: Oviparous female. a, Right antenna. (Original.)

body, 1.51 mm.; width of body, 0.76 mm.; antennæ, joint I, 0.063 mm.; joint II, 0.048 mm.; joint III, 0.136 mm.; joint IV, 0.083 mm.; joint V, 0.085 mm.; joint VI, 0.086 mm.; filament, 0.021 mm.

Described from specimens collected at Walnut Creek, Cal., and San Jose, Cal., October 16 to 26, 1912.

THE OVIPAROUS FEMALE, ADULT STAGE (FIG. 7).

General color gamboge, varying in newly molted examples to lemon yellow and in older individuals to salmon pink or with a distinct brownish tint. Eyes crimson. Head and prothorax with indefinite dusky brown markings. Ocular tubercles small. Anterior margin of the head with six capitate hairs

projecting forward. Thorax mottled all over with shades of brown, its lateral margins lighter. Prothorax with two capitate hairs on either side of its posterior portion. Abdomen with two or three hairs on the lateral margins of each segment. Segments 4 and 5 and posterior half of 3 with dark brown or black markings which generally coalesce to

form three transverse bars or bands, of which those on segments 4 and 5 do not quite reach the lateral margins of the segments, while that on the third segment is slightly shorter and but half as broad as the others. Wings absent. Cornicles quite similar to those of the winged viviparous female. Cauda globular, concolorous with the abdomen, larger than that of the winged viviparous female. Anal plate large, U-shaped, extending beyond the cauda when viewed from above. In reality it has a shallow incision at the apex. Antennæ on slight frontal tubercles, reaching to the middle of the meta-thoracic segment, white, with the apices of joints 3 to 6 black. Legs very pale yellow, almost hyaline; tarsi dusky gray at their apices. All six femora have the characteristic black or brown knee spot. Beak yellow, the extreme tip black, reaching to the second coxæ. Hind tibiæ not much swollen, bearing about 35 circular sensoria occurring evenly on the middle two-thirds of the tibia and arranged in an irregular spiral. Measurements: Length of body, 1.60 mm.; width of body, 0.81 mm.; antenna, joint I, 0.06 mm.; joint II, 0.04 mm.; joint III, 0.22 mm.; joint IV, 0.125 mm.; joint V, 0.109 mm.; joint VI, 0.081 mm.; filament, 0.023 mm. Cornicles, 0.06 mm. Cauda, 0.085 mm.

Described from specimens collected in the fall of 1911 at San Jose, Cal.

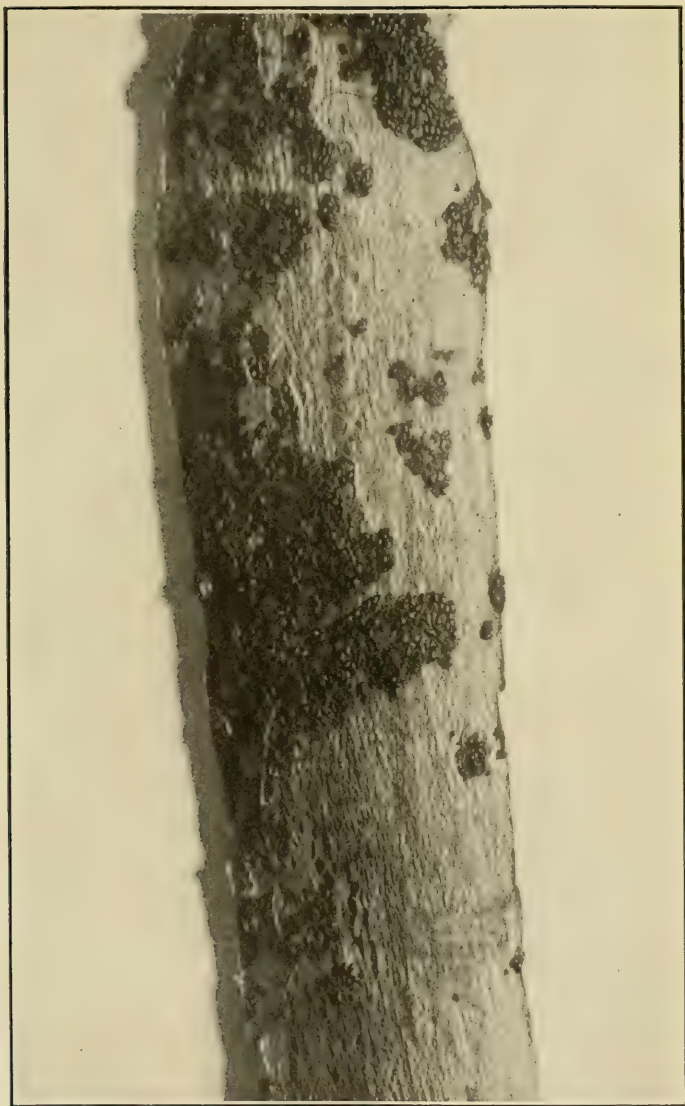
THE FULL-GROWN MALE PUPA.

In its immature stages the male pupa resembles the oviparous female. A description of a single full-grown male pupa taken at San Jose, Cal., October 27, 1912, is as follows:

General color pale lemon yellow. Antennæ pale, whitish, reaching to the anterior margin of the metathorax; last three joints black or dusky. Head and prothorax brownish. Eyes bright red. Wing pads very pale. Legs entirely whitish, only the hind femora bearing the characteristic knee spot; tarsi dusky gray. Cornicles as broad as long. Cauda very small, rounded. Cornicles and cauda pale yellow. Head, thorax, and abdomen with two longitudinal dorsal rows of oval black spots and with two such lateral rows of circular black spots. On each of these spots is situated a tubercle having a single capitate hair. Excluding the wing pads the body resembles that of the immature sexual female. Measurements: Length of body, 1.01 mm.; width of body, 0.50 mm.; antenna, joint I, 0.049 mm.; joint II, 0.035 mm.; joint III, 0.121 mm.; joint IV, 0.081 mm.; joint V, 0.087 mm.; joint VI, 0.063 mm.; filament, 0.023 mm.

THE WINGED MALE, ADULT STAGE (FIG. 8).

General color of the body pale yellow or greenish yellow. Head, prothorax, and thorax grayish black. Scutellum black. Eyes bright red. Antennæ not on frontal tubercles, reaching to the posterior margin of the first abdominal segment, pale yellow; joints I and II, the filament or spur, and the articulations of joints III to VI dusky gray. These dark articular annulations are less pronounced than in the viviparous female. Wings of medium size; costa, subcosta, and insertions pale yellowish gray; stigma short and gray, with its central area paler; veins gray, second fork of third discoidal nearer to the wing apex than to the first fork and arising beyond the apex of the stigmatic vein; stigmatic vein evenly and gently curved, absent in the middle for a space equal to one-third of its length. Legs longer in proportion to the body than those of the other forms; front legs and middle tibiæ very pale yellow or yellowish green; distal two-thirds of the middle and hind femora shaded gray, the black knee spot being present on these four femora; hind tibiæ shaded gray for its proximal three-fourths, its apical fourth pale yellow; all tarsi light gray. Abdomen barely as long as the head and thorax combined, widest at the fourth segment, and with a pair of



EGGS OF EUROPEAN WALNUT APHIS (*CHROMAPHIS JUGLANDICOLA*) ON
PIECE OF BARK OF EUROPEAN SEEDLING WALNUT. TWICE NATURAL
SIZE.

oval gray transverse spots on the fifth segment, which are separated by a space equal to their length. Cornicles pale yellow, about as broad at the base as long, very much as in the winged female. Cauda pale yellow, globular, not quite as long as the hind tarsus. Sexual organ pale yellow. Beak pale yellow, slightly exceeding the fore coxæ. Sterna black. Sensoria transversely oval, situated in an irregular row as follows; joint III, 11 to 16; joint IV, 5 to 7; joint V, 4 to 5; joint VI, 2 besides usual terminal. •

Measurements: Length of body (average), 1.47 mm.; width of body (maximum), 0.48 mm.; expanse of wings (average), 4.20 mm; antenna, joint I, 0.05 mm.; joint II, 0.04 mm.; joint III, 0.34 mm.; joint IV, 0.12 mm.; joint V, 0.12 mm.; joint VI, 0.08 mm.; filament, 0.03 mm.; cornicles, 0.05 mm.



FIG. 8.—*Chromaphis juglandicola*: Winged male (appendages of left side removed). a, Left antenna. (Original.)

Described from many individuals collected in 1911 and 1912 at San Jose, Cal.

Both the male and the winged viviparous female when disturbed have a habit of jumping psyllid-like into the air. Their flight is generally in the form of a long spiral, and when disturbed they fly in an upward direction.

EGG DEPOSITION.

As mentioned before, the first sexual females of the year remain longer on the leaves after they have reached the adult state than those developing later. In 1911 eggs were not observed in the field until September, or seven weeks after the first appearance of sexual females. In 1912 some eggs appeared in August. This long period between the first appearance of the sexed females and the

earliest egg deposition may be explained by the fact that until late in August males are quite scarce and so the females must wait on the leaves until the males are developed. Directly after mating the female repairs to the branches and limbs to deposit her eggs. Although eggs may be deposited anywhere along the limbs, and more rarely on the newer growth, the locations most preferred are the old scars of fallen leaves and the surface of the larger limbs near their bases. Another favored location is that in the crotches of the smaller limbs. Eggs are rarely laid along the stalk of the leaf or at the base of the leaflets, and if placed in those positions they fall to the ground when the leaf drops. Cavities and interstices in the bark are also chosen, but when infestation is very severe the eggs are laid in the open on the larger limbs (see Pl. II). In such a case large groups of eggs are massed together by many females, but a single female lays not more than three or four in a group. The eggs are fastened together and to the plant surface by a thin, transparent, gluey substance. No accurate information was obtained as to the number of eggs a single aphid produced, but from general field observations together with dissections of gravid females the writer arrived at the conclusion that not more than 30 eggs fell to the share of each adult, and probably not over half that number. On July 20, 1911, five gravid females were dissected. These contained respectively 5, 3, 3, 4, and 4 well-developed ova, besides about a dozen much smaller ones. On August 28, 1912, four oviparous females dissected contained respectively 2, 2, 4, and 2 full-grown ova besides about 20 much smaller ones. All these individuals were taken on the leaves and had not oviposited. The largest eggs dissected were lozenge-shaped and measured 0.37 mm. in length by 0.14 mm. in width.

THE EGG (FIG. 1; PL. II).

When first laid, the egg is pale lemon-yellow or whitish yellow, oval, almost twice as long as broad, flatter than most eggs of Aphididae, and slightly broader at the micropylar end. After two or three days it turns black and shines obscurely when placed under a strong light. The surface is beautifully sculptured with granular hexagonal markings. These markings are thickened portions of the shell. The narrow intermediate portions of the shell are extremely thin, so much so that four months after the egg has been laid the yellow interior substance is plainly visible through them if subjected to a high power of magnification. It appears that about 85 per cent of the eggs are fertile. The average size is 0.50 mm. by 0.28 mm. The egg stage may be said to occupy, on the average, five months in California.

ANT ATTENDANTS.

The sweet juices excreted by the European walnut aphid attract large numbers of ants, of which a large black species, *Formica subsericea* Say, is the most abundant. The author is indebted to Mr. Theo. Pergande, of the Bureau of Entomology, Washington, D. C., for the determination of this species.

THE AMERICAN WALNUT APHIS (*Monellia caryae* Monell).¹

*Callipterus*² *caryae* Monell, U. S. Geol. & Geog. Survey Bul. 5, No. 1, p. 31, Jan. 22, 1879.

*Monellia*³ *caryae* Gillette, Jour. Econ. Ent., v. 3, No. 4, p. 367, fig. 6, Aug., 1910.

HISTORY OF THE SPECIES.

This plant-louse was first collected in Missouri by Mr. J. T. Monell in 1879. His original description is as follows:

Winged form; general color pale yellow; tips of antennal joints black; legs entirely pale whitish. Antennæ a little shorter than the body; seventh joint equal to or one-third longer than the preceding; fifth joint as long as the two following taken together. Nectaries not perceptible. Rostrum not reaching to the middle coxæ. Wings hyaline, veins pale; stigma rather short and blunt at the apex. Stigmal vein subobsolete, its course being only traced with difficulty. The distance between the apex of the lower cubital branch and that of the second discoidal equal to about one-half the distance between the apices of the first and second discoidals. Apterous viviparous females and pupæ with four rows of tubercles, each mounted with a capitate bristle.

Leaves of walnut, hickory and pecan. June-July, St. Louis, Mo.

This aphid has been reported from Illinois (Thomas, 1880; Davis, 1910), Nebraska (Williams, 1910), Oregon (Gillette, 1910), and Michigan (Gillette, 1910), and doubtless occurs in America wherever its food plants grow.

GENERAL DESCRIPTION; CHARACTER AND EXTENT OF INJURY.

This aphid is about one-sixteenth of an inch long and about one-third as wide and is generally of a pale lemon-yellow color. It occurs on the lower surface of the leaf and on the nutlets of the eastern black walnut tree and crosses derived from it. When infestation is severe, the aphides will also be found on the upper surface of the leaves. The species, according to Mr. Monell and other writers, feeds also on hickories and pecan. The character and extent of its injury is altogether similar to that of the European walnut aphid (*Chromaphis juglandicola* Kalt.). This plant-louse does not lie so flatly appressed to the plant surface as the European species and is much more active, bearing longer legs and antennæ in proportion

¹ Mr. J. T. Monell, of the Bureau of Entomology, has kindly identified the specimens sent to him by the author as *Monellia caryae* Monell.

² The genus *Callipterus* ("beautiful-winged") was erected by Koch (1855).

³ The genus *Monellia* was erected by Oestlund (1887), with *caryella* Fitch as the type species.

to the size of the body. When on the lower surface of the leaflet it has the habit of resting with the head directed straight toward the peduncle of the leaflet. In July and August, in which months this insect is most abundant, as many as 400 individuals may be found on one leaflet, 5 per cent of which will be resting on the upper side. At this time it is much sought after by ants, which feed on the liquid excreted by it. A large red and black species, determined by Mr. Theodore Pergande as *Formica obscuriventris* Mayr, is a very common attendant. *Formica subsericea* Say also attends it. The sweet excretions of the aphid attract many flies of the families Muscidae, Anthomyiidae, Oscinidae, and Syrphidae, many large bees including the honeybee, wasps of the family Pompilidae, and parasitic wasps of the families Ichneumonidae and Braconidae, and numerous smaller forms of insect life. The author first observed this aphid on July 20, 1911, at San Jose, Cal.

LIFE HISTORY AND TECHNICAL DESCRIPTIONS.

THE VIVIPAROUS OR ASEXUAL FORMS.

The stem-mothers hatch as soon as the buds start to swell, about the 1st of April. These develop into winged aphides and pass their life cycle in from 25 to 30 days, according to temperature and the amount of food supply. The viviparous aphid passes through four molts, becoming winged after the final one. Table VII indicates the life cycle of 38 individuals of the summer generations.

TABLE VII.—*Life-cycle of viviparous females of Monellia caryae, summer generations, San Jose, Cal., 1912.*

No. of individual.	Generation.	Date of deposition.	Date of acquiring wings.	Life cycle.	No. of individual.	Generation.	Date of deposition.	Date of reaching maturity.	Life cycle.
				Days.					Days.
1.....	II	Apr. 22	May 12	20	20.....	V	June 22	July 7	15
2.....	II	22	12	20	21.....	V	23	7	14
3.....	II	22	12	20	22.....	V	23	7	14
4.....	II	May 1	20	19	23.....	V	24	7	13
5.....	II	1	22	21	24.....	V	24	7	13
6.....	II	1	23	22	25.....	V	24	7	13
7.....	II	1	23	22	26.....	V	24	8	14
8.....	III	13	29	16	27.....	V	24	8	14
9.....	III	13	29	16	28.....	V	24	8	14
10.....	III	13	29	16	29.....	V	25	8	13
11.....	III	13	29	16	30.....	V	25	8	13
12.....	III	13	29	16	31.....	V	25	8	13
13.....	III	13	30	17	32.....	V	25	8	13
14.....	III	13	30	17	33.....	V	25	9	14
15.....	III	13	30	17	34.....	V	27	10	13
16.....	III	13	30	17	35.....	V	27	10	13
17.....	III	13	30	17	36.....	V	27	10	13
18.....	V	June 22	July 4	12	37.....	V	27	10	13
19.....	V	22	7	15	38.....	VI	July 13	Aug. 1	19

Thus, the second generation requires 20 days, the third 16 or 17, and the fifth 15, in which to complete the life cycle. Records of the fourth generation were not obtained owing to premature death of all

individuals of this generation of which the date of deposition had been ascertained. Individuals of the fourth generation probably mature in an average of 16 days. The leaves of the Eastern black walnut fall earlier than those of the European or California black types, and consequently the viviparous aphides are not found so late on the trees. There are probably not more than nine generations of these in a year.

Immediately after passing the final molt the aphides begin depositing young. These are entirely pale lemon-yellow with red eyes and four longitudinal rows of capitate hairs and do not exceed 0.70 mm. in length. From 10 to 20 young are produced by a single female, dependent on the season of the year. The earlier generations are more prolific. After midsummer the progeny becomes smaller and smaller with successive broods.

THE PUPA OF THE WINGED VIVIPAROUS FEMALE (FIG. 9).

After the second molt the pupal wing pads are apparent as small emarginations on the sides of the thorax, but after the following molt they are much more readily seen. The pupa of the winged viviparous female may be described as follows:

Color generally pale lemon-yellow, sometimes white; head often with a reddish tinge. Antennæ on small frontal tubercles, pale yellow, with the filament and articulations of joints 3 to 6 dusky black. Eyes bright red. Thoracic segments and wing pads light yellow, wing pads projecting out from the body at a very acute angle. Legs pale, tarsal apices dusky. Body beset with long capitate spines in four rows. Cornicles on segment 6 of the abdomen, hardly perceptible, broader than long. Cauda blunt, conical, and short. Cornicles and cauda concolorous with the abdomen. Beak pale, reaching to the middle coxæ. Measurements: Length of body (average), 1.87 mm.; width of body (average), 0.71 mm.; antenna, joint I, 0.058 mm.; joint II, 0.050 mm.; joint III, 0.287 mm.; joint IV, 0.207 mm.; joint V, 0.201 mm.; joint VI, 0.128 mm.; filament, 0.136 mm.

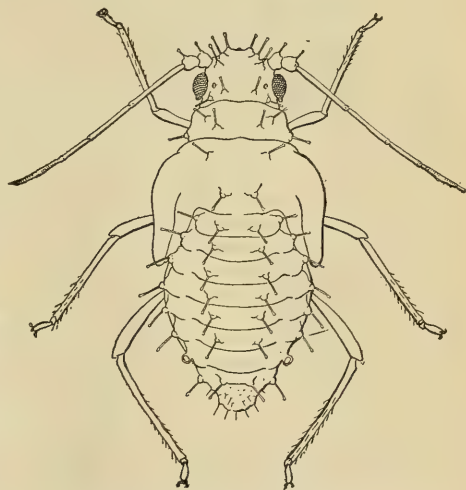


FIG. 9.—*Monellia caryæ*: Pupa of winged viviparous female. (Original.)

This pupa is distinguishable from that of *Chromaphis* by the presence of the dorsal rows of spines and by the absence of the black femoral spots. The penultimate instar occupies on the average four or five days. At its termination the final molt occurs, and after this the insect has acquired its full development.

THE WINGED VIVIPAROUS FEMALE (FIG. 10).

General color pale lemon-yellow; many examples are greenish yellow and others decidedly pinkish. Head, thoracic lobes, and scutellum pale brown or yellowish brown. Eyes pink. Antennae on small frontal tubercles, about half as long as the body, pale yellow, with articulations of joints III to VI black; joint III the longest, not noticeably thickened basally; joint IV slightly longer than V and barely as long as joint VI, together with its spur or filament. Bases of antennae encircled, in the majority of individuals, with a narrow dusky ring. Close to the lateral margins of the prothorax and roughly parallel to them occur two narrow black lines. (These are sometimes absent.) Wings of moderate size; costa, subcosta, and stigma pale yellowish green, other veins light brown, of medium thickness. Stigmatic vein entirely subobsolete, its course not easily made out. Legs very pale, whitish, tarsi and apex

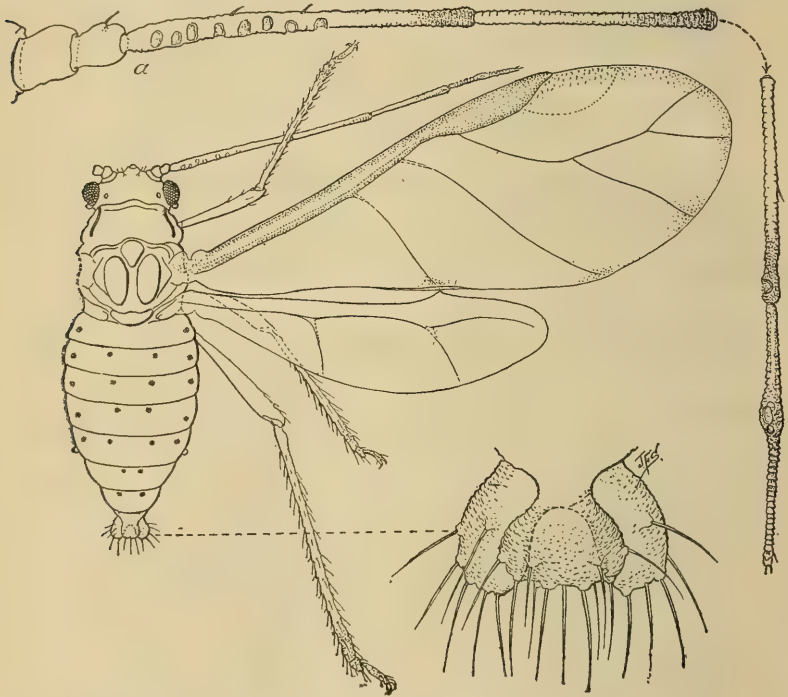


FIG. 10.—*Monellia caryæ*: Winged viviparous female. a, Antenna. (Original.)

of tibiae dusky grey; anterior and posterior femora in about half of the individuals bear a grey knee spot quite like that of *Chromaphis juglandicola* Kalt. but smaller. This spot never occurs on the middle femora. Abdomen pale yellow, sometimes greenish and at other times reddish, with four rows of small black spots, which are very variable and often wholly absent. The two lateral rows have larger spots and these are found on segments 2-6; the two median rows are smaller and their spots exist on segments 2-8. Cornicles on segment 6, hardly perceptible, more than twice as broad as long, about 0.008 mm. long. Cauda globular, shorter than the hind tarsus. Cornicles and cauda concolorous with the abdomen. Anal plate bifid, armed with spines. Beak pale, extreme tip brown and not quite extending to the second pair of coxae. Sensoria occur on the antennae as follows: Joint III, 6-9 transversely oval on basal half or two-thirds of joint; in an equally spaced row; joint V, 1 terminal; joint VI, 4 terminal (1 large, 3 small). Measurements: Length of body, 2.16 mm.; width of

body, 0.754 mm.; wing expanse, 4.44 mm. Antenna, joint I, 0.076 mm.; joint II 0.060 mm.; joint III, 0.416 mm.; joint IV, 0.273 mm.; joint V, 0.273 mm.; joint VI, 0.143 mm.; filament, 0.164 mm.

Described from many specimens taken at San Jose, Cal., during 1911 and 1912.

The complete absence of the stigmatic vein and the relatively longer antennæ, together with the diminutive cornicles, will readily distinguish this species from the European walnut aphid.

In 18 months' study of this plant-louse the author has failed to find any trace of the existence of a wingless viviparous form.

THE OVIPAROUS OR SEXUAL FORMS.

If a tree be heavily infested, the sexual forms appear first about the middle of July and probably belong to the fifth and sixth generations. If infestation be only moderate or slight, these forms are not produced until several weeks later and will be members of the seventh and following generations. The sexed forms from the beginning are produced in comparative abundance and comprise from 30 to 50 per cent of the whole. The young sexed females are paler and more spindle-shaped than the young of the viviparous individuals, while the male larvæ and pupæ are conspicuously brick-red in color. The male is not so greatly outnumbered by the female as in the European walnut aphid, and from the first comprises from 20 to 30 per cent of the sexed insects. On August 26 and 27 and September 5, 1912, a count of the forms on 34 leaflets taken at random from an Eastern black walnut tree showed 177 viviparous females, 14 males, and 26 sexed females. Probably as many again of the sexed females in proportion to the leaflets counted could be found on the twigs ovipositing. Copulation takes place on the leaf and occupies half a minute. All through August and September, 1912, the oviparous females were observed on the twigs, but few eggs were found until September. After the middle of September few aphides were found, the great majority having been destroyed by their natural enemies, but those that escape perpetuate the species until the leaves fall in November. The majority of aphides born in the late fall are sexual. The sexed female shortly after mating becomes much swollen by reason of the growing ova in her body, and the last four abdominal segments become orange colored. She repairs to the twigs and limbs and wanders around searching for locations wherein to oviposit. Occasionally immature females wander off to the twigs, but later return to the leaves to resume feeding. The fully mature fertilized oviparous female once she has forsaken the leaf rarely if ever returns, and thus escapes many predatory foes. Having found a crevice or crack in the cortex suitable for her purpose she grips the limb with

her six legs and bends the hind part of the abdomen at a right angle to the rest of the body and then gives her abdomen a succession of jerks to get it into place. This performed to her satisfaction, she remains motionless for 60 seconds while the egg is being extruded, and after depositing it walks off. The writer has never seen the eggs of this species placed in an open situation, but always in some protected position in the bark. On August 28, 1912, four gravid females were dissected and were found to contain respectively 3, 4, 2, and 4 large eggs, and all had several smaller ones. Another had 8 large eggs in her ovaries and was greatly distended therefrom. The egg is bluntly oval, bright yellow when first laid, but changing in a day or two to black and obscurely shining. It measures 0.35 mm. in length and 0.17 mm. in width, and is therefore considerably smaller than the egg of the European walnut plant-louse. The oviparous forms are described below.

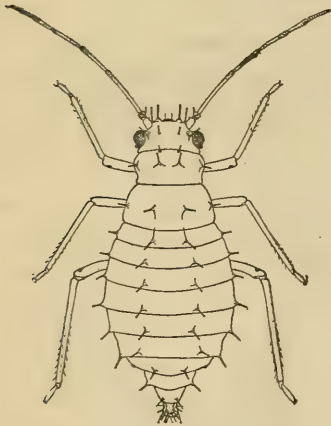


FIG. 11.—*Monellia caryæ*: Oviparous female. (Original.)

THE OVIPAROUS FEMALE, FULL GROWN (FIG. 11).

General color pale greenish yellow or sometimes greenish white, the four apical segments of the abdomen at first colored like the rest of the body and later orange colored. Body rather narrow, not at all flattened, the sides nearly parallel and produced posteriorly into a conical tube. Antennæ a little over one-half the body in length, pale, with the apical third or fourth of joints III to VI dusky gray; joint II gray and armed with a capitate spine on its inner margin; joint III longest; joints IV and V subequal; joint VI shorter than its spur or filament. Legs very pale yellow, with a dark spot close to the apex of the anterior and posterior femora. (In many individuals these spots are absent.) Eyes pink. The

arrangement of capitate spines is as follows: The head bears eight, the prothorax six, the mesothorax, metathorax, and abdominal segments 1 to 5, inclusive, four, and abdominal segments 6, 7, and 8 two; these spines appear as four longitudinal rows. Cornicles greenish yellow, broader than long, hardly perceptible, located on segment 6. Cauda concolorous with the body, globular, armed with four noncapitate spines, half as long as the hind tarsus. Genital plate protruding beyond the cauda, pale, its margin beset with short noncapitate hairs. Beak pale, its extreme tip brownish, just exceeding the second pair of coxæ. Measurements: Length of body, 1.68 mm.; width of body, 0.72 mm.; cauda, 0.038 mm.; antenna joint I, 0.04 mm.; joint II, 0.035 mm.; joint III, 0.300 mm.; joint IV, 0.17 mm.; joint V, 0.17 mm.; joint VI, 0.100 mm.; filament, 0.12 mm.

Described from many specimens collected at San Jose, Cal., during 1912.

YOUNG MALE PUPA.

Light red in general color; appressed closely to the leaf surface. Dorsum of head in front black, behind gray. Dorsum of thorax gray. Antennæ six-jointed (i. e., with five joints and filament), one-third as long as the body, pale gray. Eyes bright red. Legs pale, femora dusky gray. Mesothorax, metathorax, and first five abdominal segments each with four black spots in a transverse row. Abdominal segments 6 to 8, inclusive, with two such spots. A single capitate spine arises from each of these spots. Cornicles imperceptible. Cauda pale, short, conical. Beak pale, tip dusky gray, reaching first coxæ.

FULL-GROWN MALE PUPA (FIG. 12).

General color pale brick red; head pale orange. Antennæ half as long as the body, seven-jointed, pale yellow, with dusky articulations. Eyes bright red. Legs very pale, femora usually slightly dusky. Wing pads white. Whole body with four longitudinal rows of dark capitate spines distributed as in the oviparous female. Cornicles on segment 6, appearing as little rims on the body surface, broader than long, concolorous with the body. Cauda bluntly conical, very short, pale yellow. Beak pale yellow, extreme tip brown, reaching to the first pair of coxæ. Measurements: Length of body, 1.58 mm.; width of body, 0.57 mm.; cauda, 0.045 mm. Antenna, joint I, 0.071 mm.; joint II, 0.054 mm.; joint III, 0.257 mm.; joint IV, 0.173 mm.; joint V, 0.200 mm.; joint VI, 0.12 mm.; filament, 0.12 mm.

Described from several specimens collected at San Jose, Cal., in 1912.

WINGED MALE (FIGS. 13; 18, a).

General color pale lemon-yellow or greenish yellow; head and a median quadrilateral area on thorax dark brown; scutellum dark brown; eyes dark red. Antennæ not mounted on frontal tubercles, about as long as the body; joints I and II with a dusky central part; joints III to VI pale, with their apices dusky gray; filament pale; joint III longest, bearing about 24 small oval sensoria; joints IV and V subequal, both bearing 10 to 15 small sensoria arranged along the outer margin; joint VI bearing 4 sensoria, of which the most distal is apical; joint VI longer than the filament, the two together scarcely as long as joint V. Ocelli distinct. Wings of medium size; costa and insertions greenish yellow; stigma short and moderately broad, dusky gray, with a large paler central area; veins brown, the third discoidal curving considerably to meet its second fork; second fork twice as near to the first fork as to the apex of the wing; stigmatic vein obsolete in its middle portion. Legs longer in proportion to the body than in the winged viviparous female, pale greenish yellow, with a large dusky area near the apex of all six femora; apices of tibiæ and tarsi dusky gray. Abdomen short, not quite as long as the head and thorax together, widest at the third segment; segments 1 to 7, inclusive, with two lateral black spots, one on each side; segments 1 to 6, inclusive, and segment 8 with two dorsal black spots, one on either side of the dorso-median line; the lateral spots on segments 1 to 6, inclusive, are circular or sub-circular; the dorsal pairs on these segments are oval; the dorsal spots on segments 6 and 8 coalesce narrowly in the middle. Cornicles on segment 6, hardly perceptible, broader than long. Cauda globular, dusky, half as long as the hind tarsus. Repro-

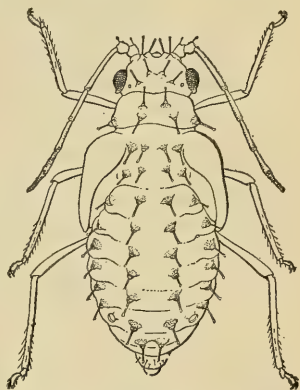


FIG. 12.—*Monellia caryæ*: Male pupa.
(Original.)

ductive organ white, when extended about as long as antennal joint IV. Beak pale yellow, extending a little beyond the first pair of coxæ. Sterna and apical half of the underside of the head dark brown. Very often one or more of the dusky abdominal spots are absent. Measurements: Length of body, 1.39 mm.; width of body, 0.69 mm.; wing expanse, 4.10 mm.; cauda, 0.049 mm.; antennal joint I, 0.051 mm.; joint II, 0.058 mm.; joint III, 0.362 mm.; joint IV, 0.238 mm.; joint V, 0.240 mm.; joint VI, 0.114 mm.; filament, 0.134 mm.

Described from four specimens collected at San Jose, Cal., in 1912.



FIG. 13.—*Monellia caryæ*: Winged male. a, Left antenna. (Original.)

THE LITTLE HICKORY APHIS (*Monellia caryella* Fitch).

Aphis caryella Fitch, [First] Report on the noxious, beneficial, and other insects of the State of New York, Albany, p. 163-165, 1855.

Callipterus caryellus Fitch, Third report on the noxious and other insects of the State of New York, Albany, p. 448-449, 1856.

Monellia caryella, Oestlund, Geol. & Nat. Hist. Survey Minn. Bul. 4, p. 45, 1887.

HISTORY OF THE SPECIES.

The little hickory aphis was first collected in New York State by Dr. Asa Fitch, previous to the year 1855. The following is Fitch's original description:

The Little Hickory Aphis (*Aphis caryella*) is pale yellow with white antennæ which are alternated with black rings, the wings are transparent and without spots, their veins slender and pale yellow, the legs yellowish white to their ends. Length 0.12 to the tips of the wings. The abdomen is depressed, egg-shaped, its apex slightly

narrowed and elongated. The antennæ are longer than the body, tapering, seven-jointed; two basal joints as broad as long, twice the diameter of the following joints; third joint longest, slightly thicker towards its base; fourth and fifth joints rather shorter than the third, cylindric; two last joints together about equalling the fifth in length; the sixth swelled at its tip into a long oval knob, the seventh more slender but not capillary, shorter than the sixth; a broad black band at the base of the third and each of the following joints. First vein of the fore wings straight and almost transverse; second vein bent near its base, running first towards the apex and then turning rather abruptly and continuing straight to the inner margin, more than twice as far from the first at tip as base; third vein arising from the stigma near its anterior end, and not from the rib-vein forward of the stigma, as it does in the aphides generally, except those pertaining to this group, its base and its apex about the same distance from the second vein that this is from the first, forking rather forward of its middle, strongly bent at this point, and from hence to its tip parallel with the third vein or but slightly diverging from it, its tip a third nearer that of the third vein than this is to the second; second fork nearer the fourth vein at tip than to the first fork, the triangular cell between it and the first fork with its three sides equal; fourth vein short and often nearly abortive, shorter than the second fork, equally curved through its whole length, its tip much nearer that of the rib-vein than that of the second fork; rib-vein very slightly diverging from the margin from the base to the stigma, curved from thence to its tip. Stigma oval, about twice as long as wide, watery, sometimes tinged with yellowish. A variety has the stigma dusky at its tip. Another variety (*costalis*) has the rib-vein coal black interrupted with whitish towards the stigma, which is dusky and black at each end.

In a general discussion of this species before his description Fitch refers to the minute cornicles characteristic of this and kindred species. In his third report on the insects of New York he mentions the European walnut aphid and says "European *C. juglandicola* of Koch" [*Chromaphis juglandicola* Kalt.] "appears closely related to this present species" [i. e. *Callipterus caryellus*]. Fitch gave the host plant of his species as the hickory. Oestlund (1887) reports it in Minnesota from *Carya amara* Nutt. Davis (1910) and other Eastern writers record it from hickory in the Eastern States. In California the normal food plants are the California black walnut (*Juglans californica*) and hybrids derived from this tree.

GENERAL APPEARANCE; CHARACTER AND EXTENT OF INJURY.

In general appearance this aphid is very similar to the American walnut aphid (*Monellia caryæ* Monell) and can not be distinguished from it except when viewed under the microscope or a powerful hand magnifier. Its habits of life and the character and extent of its injury are also very similar to those of *M. caryæ*. The writer had observed this aphid for several months before he realized that it was a distinct species and not a variety of *caryæ*, as he had previously supposed. When the sexed forms appeared it was noticed that the oviparous female of *caryella* differed markedly from the same form of *caryæ*, and this led to a closer scrutiny of the viviparous form resulting in the establishment of the points of divergence shown in Table VIII.

TABLE VIII.—Divergences of structure between *Monellia caryæ* Monell and *M. caryella* Fitch.

Form.	<i>Monellia caryæ</i> Monell.	<i>Monellia caryella</i> Fitch.
Winged viviparous female.....	Antennal joint III very slightly thickened basally. Sensoria on antennal joint III occupying basal half or two-thirds. Antennal joint VI and its spur or filament subequal, or VI less than spur. Dusky knee spots often present.	Antennal joint III quite noticeably thickened for its basal half. Sensoria on antennal joint III occupying basal third. Antennal joint VI one-third as long again as its spur or filament. Dusky knee spots absent.
Pupa of viviparous female.....	Four longitudinal rows of capitate spines.	Six longitudinal rows of capitate spines.
Oviparous female.....	Smaller than the viviparous female. Four longitudinal rows of capitate spines.	Larger than the viviparous female. Six longitudinal rows of capitate spines.

LIFE HISTORY AND TECHNICAL DESCRIPTIONS.

Life-history studies on this plant-louse began in August, 1912, at San Jose, Cal., but no rearing work was done until the appearance of the sexed forms in September. Observations taken in August and September indicated a development of the summer generations similar to that found in *Monellia caryæ*. This was further confirmed by studies during 1913. The sexed forms were studied at Walnut Creek and San Jose, Cal. In both localities these did not appear until late in September, even on trees heavily infested. The aphides remained on the trees as long as there were leaves on which they could subsist and were to be found until mid-November. After September the great majority of aphides deposited were oviparous, and of these the males were extraordinarily scarce, the writer observing only one individual of this sex among hundreds of oviparous females. Table IX indicates the life cycle of plant-lice deposited by four viviparous females and shows the preponderance of the sexed form over the asexual in the late fall.

TABLE IX.—Life-cycle record of the progeny of four viviparous females of *Monellia caryella*, Walnut Creek, Cal., 1912.

FEMALE NO. 1; DEPOSITED 3 YOUNG.

No. of larva.	Date of—					Form of individual.	Life cycle.
	Hatching.	Molt 1.	Molt 2.	Molt 3.	Molt 4 (becoming adult).		
1.....	Oct. 4	Oct. 7	Oct. 10	(?)	Oct. 16	Winged viviparous female.	Days. 12
2.....	4	7	11	(?)	18	Oviparous female.	14
3.....						do.	

FEMALE NO. 2; DEPOSITED 6 YOUNG.

1.....	Oct. 12	Oct. 15	Oct. 18	Oct. 21	Oct. 28	Oviparous female.	16
2.....	12	15	18	21	28	do.	16
3.....	12	15	19	22	29	do.	17
4.....	12	15	19	23	30	do.	18
5.....	12	(?)	(?)	(?)	29	do.	17
6.....	12	(?)	(?)	(?)	30	do.	18

¹ Died prematurely.

TABLE IX.—*Life-cycle record of the progeny of four viviparous females of Monellia caryella, Walnut Creek, Cal., 1912—Continued.*

FEMALE NO. 3; DEPOSITED 16 YOUNG.

No. of larva.	Date of—					Form of individual.	Life cycle.
	Hatch- ing.	Molt 1.	Molt 2.	Molt 3.	Molt 4 (becom- ing adult).		
1.....	Oct. 16	Oct. 21	Oct. 27	Nov. 3	Nov. 7	Oviparous female.....	Days. 22
2.....	16	21	27	3	7	do.....	22
3.....	16	21	27	3	7	do.....	22
4.....	17	(?)	(?)	(?)	8	do.....	22
5.....	17	(?)	(?)	(?)	8	do.....	22
6.....	17	(?)	(?)	(?)	8	do.....	22
7.....	17	(?)	(?)	(?)	8	do.....	22
8.....	18	(?)	(?)	(?)	8	do.....	21
9.....	18	(?)	(?)	(?)	9	do.....	22
10 ¹						do.....	
11 ¹						do.....	
12 ¹						do.....	
13 ¹						do.....	
14 ¹						do.....	
15 ¹						do.....	
16 ¹						do.....	

FEMALE NO. 4; DEPOSITED 8 YOUNG.

1.....	Oct. 18	Oct. 22	Oct. 27	Nov. 2	Nov. 7	Oviparous female.....	20
2.....	18	22	27	3	9	do.....	22
3.....	18	22	27	4	9	do.....	22
4.....	18	22	27	4	9	do.....	22
5 ¹						do.....	
6 ¹						do.....	
7 ¹						do.....	
8 ¹						do.....	

¹ Died prematurely.

SUMMARY.

Life cycle (20 oviparous females).	Days.
Maximum.....	22
Minimum.....	14
Average.....	18.92
First instar (13 individuals), average...	3.7
Second instar (13 individuals), average...	4.5
Third instar (11 individuals), average...	5.7
Fourth instar (11 individuals), average...	5.6

The viviparous forms, so far as the author has observed, all develop wings.

The eggs of this aphid are larger than those of the American walnut aphid and measure on the average 0.536 mm. in length and 0.222 mm. in maximum width. They are elongate-oval in shape, rather feebly shining, and have a softer shell than is found in the eggs of the majority of plant-lice, but one not so soft as is that of *Chromaphis juglandicola*. They are placed either singly or in groups of two or three around the axils of the buds or in crevices in the bark and in scars caused by fallen leaves on the smaller limbs and twigs. Oviposition is in progress during the months of October and November, each oviparous female laying on the average about 12 eggs. Owing to the

scarcity of males in the fall of 1912 at Walnut Creek, Cal., it seemed very probable that a large proportion of the eggs would prove to be sterile, and in the following spring examinations of egg-infested trees showed this assumption to be correct.

THE VIVIPAROUS FORMS.

The stem-mothers commence hatching very shortly after the leaf buds open in the latter part of March. Previous to the first molt they are pale lemon-yellow with red eyes, hyaline legs, and dusky tarsi; the joints of the antennæ have black articulations; on the abdomen are four longitudinal rows of circular dusky spots from each of which arises a capitate spine. They are destined to become winged and in their later stages do not differ from the summer winged viviparous individuals.



FIG. 14.—*Monellia caryella*: Pupa of winged viviparous female. (Original.)

THE PUPA OF THE WINGED VIVIPAROUS FEMALE (FIG. 14).

General color pale lemon-yellow; some individuals exhibit a decided greenish, others a decided salmon colored tinge. Antennæ two-thirds of the body in length; apices of joints III to VI and the whole filament dusky, otherwise pale yellow, almost white. Eyes bright red. Head with eight capitate spines, six of these on the frontal margin and two near the hind border. Prothorax with six capitate spines, two of these near the middle of the segment and four in a transverse row along the hind margin. Mesothorax, metathorax, and abdomen with six longitudinal rows of capitate spines. Legs pale yellow, tarsi dusky. Wing pads pale, after being imbedded in balsam for a few days becoming dusky. Cornicles barely perceptible, wider than long. Cauda rounded, not as long as the hind tarsi and without hairs. Beak pale with a brown tip, almost reaching the second pair of coxæ. Measurements: Length of body, 1.81 mm.; width of body, 0.72 mm.; antenna, joint I, 0.070 mm.; joint II, 0.050 mm.; joint III, 0.253 mm.; joint IV, 0.198 mm.; joint V, 0.183 mm.; joint VI, 0.134 mm.; filament, 0.105 mm.

Described from four specimens, Walnut Creek, Cal., October, 1912.

THE WINGED VIVIPAROUS FEMALE (FIG. 15).

General color pale lemon-yellow, somewhat varying in shade. Antennæ about four-fifths as long as the body, pale yellow, with joints III to VI, inclusive, bearing an apical black ring (on joint III this ring is narrower than the other joints); filament of joint VI dusky; joint III is the longest; joints IV and V subequal or joint IV slightly longer than V; joint IV about four-fifths as long as III; joint VI together with its filament about equal to V; filament about three-fourths as long as VI; basal third of joint III noticeably swollen and bearing from five to seven oval transverse sensoria; usual apical sensoria on both joints V and VI. Head pale yellow, with the frontal margin black. Eyes bright red. Prothorax pale yellow, with two narrow, black, longitudinal stripes arising from the anterior angles and extending for two-thirds



FIG. 15.—*Monellia caryella*: Winged viviparous female. a, Right antenna, enlarged, with variations of number of sensoria. (Original.)

of its width. Thoracic lobes and scutellum light brown, sometimes with a salmon-pink tinge. Wing insertions, costa, subcosta, and stigma pale lemon-yellow; discoidals yellowish-brown; first and second discoidals heavier than the other veins; third discoidal obsolete at its immediate base, its first fork equidistant from the second fork and the base of the discoidal, its second fork nearer to the first fork than to the apices of its two branches; branches of second fork equal in length; stigmatic vein very weak, its basal half traceable only with difficulty; lower wing colorless. Legs pale yellow; tarsi and tibial apices dusky. Abdomen entirely pale lemon-yellow, the body widest at the third segment. Body somewhat narrowed laterally. Cornicles pale yellow, hardly perceptible, wider than long. Cauda globular, bearing a fringe of weak hairs, about equal in length to the hind tarsi, concolorous with the abdomen. Genital plates armed with weak hairs, pale yellow. Beak pale yellow, its extreme tip brown, extending halfway between first and second coxæ. Measure-

ments: Length of body (average), 1.67 mm.; width of body (average), 0.61 mm.; wing expanse (average), 4.02 mm.; antenna, joint I, 0.053 mm.; joint II, 0.046 mm.; joint III, 0.41 mm.; joint IV, 0.335 mm.; joint V, 0.32 mm.; joint VI, 0.191 mm.; filament, 0.123 mm.; cauda, 0.084 mm.; Cornicles, 0.009 mm.

Described from numerous specimens, Walnut Creek, Cal., October, 1912.

THE OVIPAROUS FORMS.

THE OVIPAROUS FEMALE (FIG. 16).

Wingless. General color pale lemon-yellow, in mature individuals the central part of the abdomen diffused with orange. Body elliptical, widest at the third abdominal segment. Antennæ half as long as the body, not on frontal tubercles, pale, with

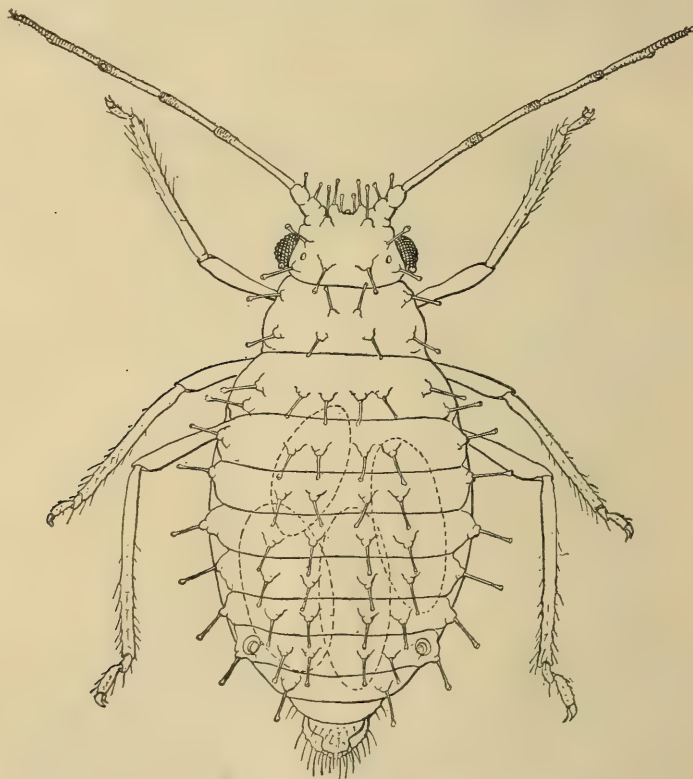


FIG. 16.—*Monellia caryella*: Oviparous female. (Original.)

an apical black ring on joints III to VI, inclusive; joints I, II, and filament dusky; joint III longest; joints IV and V subequal and each about four-fifths as long as joint III; filament a little shorter than VI; VI about four-fifths as long as V. Eyes crimson. Legs pale yellow; tarsi dusky. Hind tibiae slightly thickened. Cornicles very small, pale. Cauda pale, globular, beset with a fringe of weak hairs, not as long as the hind tarsi. Thorax and abdomen with six longitudinal rows of capitate bristles, each surmounting a pale tubercle. Penultimate segment of the abdomen encircled near its posterior margin with a fringe of weak hairs. Eight capitate spines on the

head and six on the prothorax. Tibiæ armed with a row of short bristles on their inner margins. Beak pale, the extreme tip dusky, extending a little beyond the anterior coxæ. The young oviparous female is entirely pale yellow and can be distinguished from the young viviparous female only by its more elliptical shape, that of the latter being more oval. Measurements: Length of body, 1.89 mm.; width of body, 0.92 mm.; antenna, joint I, 0.075 mm.; joint II, 0.042 mm.; joint III, 0.312 mm.; joint IV, 0.203 mm.; joint V, 0.218 mm.; joint VI, 0.167 mm.; filament, 0.108 mm. cauda, 0.080 mm.; cornicles, 0.009 mm.

Described from numerous specimens, Walnut Creek, Cal., October, 1912.

WINGED MALE (FIGS. 17; 18, *b*).

General color pale green or greenish yellow. Head and prothorax olive-green. Frontal margin of head and frontal margin of prothorax, black. Prothorax with two



FIG. 17.—*Monellia caryella*: Winged male. (Original.)

bluntly rounded dusky tubercles on the dorsum. Dorsum of head and thorax with indefinite dusky markings. Eyes red. Antennæ dark olive-green, about three-fourths of the body in length; joint VI longer than its filament. Sensoria as follows: III, about 21; IV, 7 to 9; V, 6 to 10; VI, 2 to 4 (besides the usual apical). Wings of moderate size; insertions and subcosta greenish-yellow; stigma light brown, with a paler central area; discoidals 1 and 2 thicker than the other veins and with a narrow smoky border; stigmatic vein obsolete except for its apical third; veins brown. Legs pale greenish-yellow; coxæ, trochanters, apical five-sixths of femora, and basal four-fifths of tibiæ black; tarsi gray. Thoracic lobes and scutellum black. Under the wings

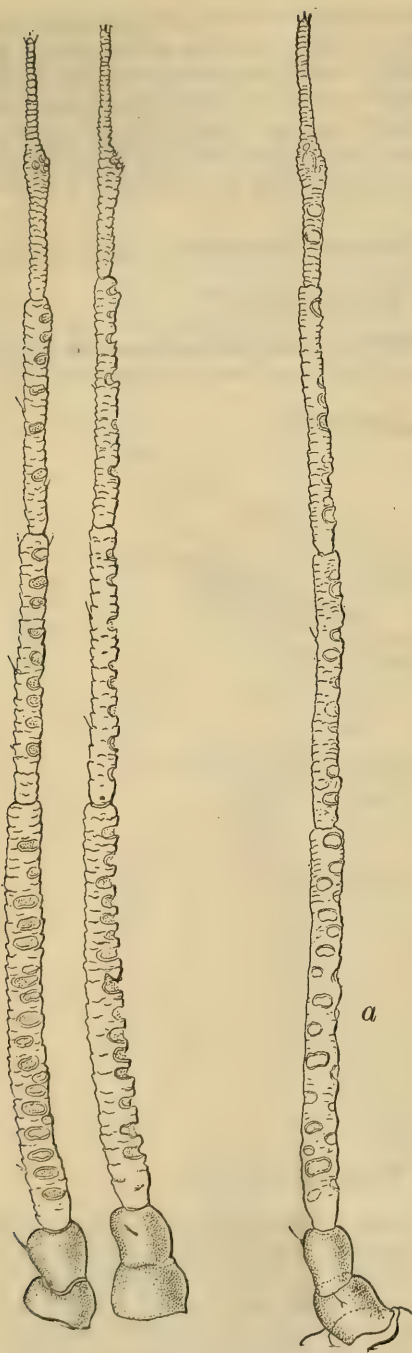


FIG. 18.—*a*, *Monellia caryæ*, antenna of male; *b*, *Monellia caryella*, two views of right antenna of male. (Original.)

occurs a large black spot on the pleuræ. Abdomen unarmed, pale green or greenish yellow; segments 1 to 8, inclusive, with two dusky brown oval spots on each. Cornicles pale, concolorous with the body, very small, considerably broader than long. Cauda concolorous with the abdomen, globular. Abdomen about as long as head and thorax combined, not wider than the thorax. Beak pale, barely reaching second coxæ. Sternum and underside of the eighth abdominal segment black.

Measurements: Length of body, 1.57 mm.; width of body, 0.62 mm.; expanse of wings, 4.62 mm.; antenna, joint I, 0.080 mm.; joint II, 0.041 mm.; joint III, 0.412 mm.; joint IV, 0.317 mm.; joint V, 0.260 mm.; joint VI, 0.175 mm.; filament, 0.108 mm.; cauda, 0.067 mm.; cornicles, 0.009 mm.

Described from three specimens, Walnut Creek, Cal., 1912 and 1913.

MONELLIA CALIFORNICA Essig.

Monellia californicus Essig, Pomona Jour. Ent., v. 4, no. 3, p. 767, Nov., 1912.

In southern California feeding on the underside of the leaves of the California black walnut (*Juglans californica*) there has recently been found a plant-louse closely allied to *Monellia caryæ* and *M. caryella*. The writer has never seen this aphid in nature, but has received specimens from Mr. Essig, who described it.

KEY TO THE SPECIES OF MONELLIA KNOWN TO OCCUR IN CALIFORNIA.

The following key will serve to distinguish the four species of walnut aphides occurring in California.

KEY TO THE SPECIES OF APHIDIDÆ KNOWN TO OCCUR ON WALNUT IN CALIFORNIA.

A. Cornicles quite evident, about as wide as long.

Chromaphis juglandicola Kalt.

AA. Cornicles barely perceptible, considerably wider than long.

B. Tibiæ of winged viviparous female entirely dusky.

Monellia californica Essig.

BB. Tibiæ of winged viviparous female for the most part pale.

C. Filament of joint VI longer than joint VI; oviparous female with four longitudinal rows of capitate hairs.... *Monellia caryæ* Monell.

CC. Filament of joint VI shorter than joint VI; oviparous female with six longitudinal rows of capitate hairs..... *Monellia caryella* Fitch.

NATURAL CONTROL OF WALNUT APHIDES.

INTERNAL PARASITES.

In July, 1912, a small chalcidid wasp was observed ovipositing in a pupa of *Monellia caryæ*. This is the only record of parasitism or attempted parasitism observed during two seasons, so there is good reason to believe that these aphides are practically immune from the attacks of internal parasites.

FUNGOUS DISEASES.

Although occasionally a plant-louse may be noticed here and there killed by fungus, only a single instance of the destruction of a colony by this agency came under the writer's notice. This occurred on May 20, 1911, following a rainstorm, and all the plant-lice on a few leaves were destroyed. The disease did not spread far, some cause or other checking the fungus shortly after its appearance.

PREDACEOUS ENEMIES.

Predaceous enemies are of prime importance in the control of plant-lice on walnuts and where the aphides occur in any numbers may always be found preying on them from June to September. Unfortunately they do not make their appearance on the walnuts until their prey has had time to do much damage to young nuts and to become abundant enough to cause collective injury to the tree. Should these predaceous forms appear in early spring they would quickly wipe out the few plant-lice present at that time and consequently their progeny would starve to death. As injury is thus done to the nuts and to the vitality of the tree before the advent of natural enemies, artificial measures must be practiced in order to insure healthy trees and perfect nut crops.

The predaceous enemies of walnut plant-lice include syrphus-fly larvæ, agromyzid larvæ, chrysopid and hemerobid larvæ, coccinellid beetles and their larvæ, *Camptobrochis brevis* Uhler (Heteroptera) and its larva, and various spiders.

SPIDERS.

The commonest spider predaceous on walnut plant lice is *Theridium placens* Keyserling. This spider may be found on the trees during the months of August and September and has a habit of curling around itself the edge of the leaf under the protection of which to deposit its egg sac. This species was determined by Mr. Nathan Banks, of the Bureau of Entomology, who says of it " * * * a species found on the Pacific coast. They do not choose their food, but from location of web are apt to get many plant lice." This and other spiders are of comparatively small economic importance in the control of aphides.

CAMPTOBROCHIS BREVIS UHLER.

Camptobrochis brevis Uhler, which was determined by Mr. Otto Heidemann, of the Bureau of Entomology, is a small black capsid, measuring in the adult stage 4.2 by 1.9 mm. Its larva is white, with conspicuous black markings. Both immature and mature individuals were observed actively and abundantly attacking plant lice during August, 1912. They do not occur in numbers earlier in the year and disappear in September. Thus their beneficial work is limited.

LEUCOPIS SP.

A fly of the family Agromyzidæ, *Leucopis* sp., in its larval state preys upon walnut plant lice from June to August. The small yellow maggots superficially resemble syrphid larvæ. They are never very abundant and are not a great factor in the control of the "lice." The life cycle in summer is completed in 24 days or less and there are several broods in California.

CHRYSID OR LACEWING FLIES.

Of scarcely less importance economically than the ladybird beetles and syrphid maggots are the active reddish-brown larvæ of the "lacewings." *Chrysopa majescula* Banks and *C. californica* Coq. are two species of economic importance in California. Table X shows the predatory activities of two larvæ of the latter species in the fall of 1912. The aphides consumed by these larvæ were of all sizes and averaged about 1.5 by 0.5 mm.

TABLE X.—*Chrysopa californica*: Predatory activities on walnut plant lice, Walnut Creek, Cal., 1912.

Larva No.	Date of—		Number "lice" eaten to molt 1.	Date of molt 2.	Number "lice" eaten, molt 1 to molt 2.	Date of spinning cocoon.	Number "lice" eaten from molt 2 to pupation.	Total "lice" eaten.	Number days feeding.
	Hatching.	Molt 1.							
1	Sept. 13	Sept. 22	11	Sept. 27	70	Oct. 8	265	346	20
2	18	21	22	26	57	7	300	379	19

Larva No. 1 ate on the average 17.3 "lice" per day, while larva No. 2 consumed 19.9 "lice" per day. The lacewing larvæ appear in numbers toward the end of June and may be found until the end of October. There are probably at least three broods, the last one wintering in the cocoon, which is white, short oval, with a central brown annulation, and is spun among the leaves or under a piece of bark. The closely allied but smaller hemerobiid larvæ also attack walnut plant lice.

SYRPHID LARVÆ.

Next to the ladybird beetles the larvæ of flies of the family Syrphidæ are of greatest importance in the natural control of walnut aphides. The author has reared the following species of Syrphidæ from larvæ collected while they were feeding on walnut aphides: *Catabomba pyrastris* Linnaeus (1911-12); *Sphærophoria melanosa* Wiliston (Aug. 24, 1912); *Sphærophoria sulphuripes* Thomson (Oct. 15, 1911); *Allograpta obliqua* Say (Aug. 6, 1912); *Eupeodes volucris* Osten Sacken (July, 1911). *Syrphus opinator* Osten Sacken, and probably other members of this genus, prey on the aphides. *Catabomba pyrastris* is the most abundant as well as the largest of these flies. Its aphidophagous capacity is almost double that of any of the other species enumerated above. Table XI indicates the predatory activities of two larvæ of the last brood of this fly.

TABLE XI.—*Catabomba pyrastris*: Predatory activities on walnut plant lice, Santa Jose, Cal., 1912.

Date.	Number of "lice" eaten by—		Date.	Number of "lice" eaten by—		Date.	Number of "lice" eaten by—	
	Larva No. 1.	Larva No. 2.		Larva No. 1.	Larva No. 2.		Larva No. 1.	Larva No. 2.
Aug. 29.....	(1)	(1)	Sept. 9.....	53	59	Sept. 18.....	92	107
30.....	4	4	10.....	65	85	19.....	50	104
31.....	15	15	11.....	76	62	20.....	36	10
Sept. 2.....	20	15	12.....	17	20	21.....	35	² 13
3.....	12	17	13.....	70	83	22.....	² 14	.....
4.....	11	17	14.....	62	77			
5.....	11	18	15.....	84	63	Total.....	959	1,035
6.....	23	36	16.....	74	83			
8.....	68	46	17.....	71	105			

¹ Hatched on this date.

² Pupated on this date.

The "lice" consumed were of a similar average size to those eaten by the chrysopid larvæ (Table X). The larva of *Catabomba pyrastris* is pale green, with three longitudinal white stripes the whole length of the body, and when fully extended exceeds half an inch in length. The anterior segments of the body are retractile, giving it a sluglike appearance. If food is plentiful the larva moves but little, although it is capable of rapid crawling over the foliage if food is scarce. A parasite, *Bassus* sp., preys upon it, often destroying as much as two-thirds

of a brood and thus reducing its economic value. The maggot of the fly pupates commonly among fallen leaves or rubbish at the base of the tree, forming a light brown puparium (sometimes dark purplish-brown, in which case the specimen is parasitized), with a paler median longitudinal stripe. The adult fly is a large, shining black form, with three interrupted, pale-yellow, arcuate cross-bands (rarely wanting), and is 12 mm. long. Syrphid larvæ may be found preying upon walnut plant lice from May to November, although they are quite scarce in the two extreme months.

LADYBIRD BEETLES (FAMILY COCCINELLIDÆ).

Ladybird beetles are the principal enemies of aphides affecting walnuts. The author has observed the following species feeding on these aphides: (1) *Olla abdominalis* Say; (2) *Adalia melanopleura* Le Conte; (3) *Coccinella juliana* Mulsant; (4) *Adalia humeralis* Say; (5) *Hippodamia convergens* Guerin; (6) *Hippodamia ambigua* Le Conte; (7) *Coccinella californica* Mannerheim; (8) *Adalia bipunctata* Linnæus; (9) *Chilocorus orbus* Casey. Nos. 1 to 8 in both adult and larval stages feed on the plant lice on the leaves, while the adults of the *Chilocorus* occasionally attack the winter eggs on the limbs. Nos. 1 to 4 are the most persistent enemies of the aphides, the others only appearing spasmodically on the trees. The *Hippodamia* group of lady birds seems to prefer such intensely gregarious plant lice as the plum louse (*Hyalopterus arundinis* Fabricius) or the bean aphid (*Aphis rumicis* Linnæus) and pay much less attention to the more sporadic varieties such as the aphides on walnuts.

Table XII indicates the predatory activities of five larvæ of *Olla abdominalis* (the ashy-gray ladybird.)

TABLE XII.—*Olla abdominalis*: Predatory activities on walnut plant lice, San Jose, Cal., 1912.

Larva No.	Date of hatching.	Date of molt 1.	Number of "lice" eaten to molt 1.	Date of molt 2.	Number of "lice" eaten, molts 1 and 2.	Date of molt 3.	Number of "lice" eaten, molts 2 to 3.	Date of pupation.	Total "lice" eaten.	Date of adult emergence.
1	Aug. 27	Aug. 30	29	Sept. 2	36	Sept. 5	91	Sept. 13	477	Sept. 22
2	31	Sept. 5	38	9	30	12	45	19	417	25
3	31	5	24	9	33	12	50	18	237	25
4	31	5	35	9	27	12	59	18	234	25
5	31	5	39	9	31	12	53	18	320	25

In all, 1,685 "lice" were eaten in 90 days, or 18.7 "lice" per day per larva. The "lice" were of similar average size to those consumed by the lacewing larvæ (Table X). It was noticed that before the first molt the ladybird larvæ would eat only very small aphides.

The following is a brief account of the stages of the ashy-gray ladybird (*Olla abdominalis*) (Pl. III). *The egg*: Yellow, later becoming

orange-colored; cylindrical, long oval, slightly tapering to either end, four times as long as broad; deposited in compact masses of from 5 to 25 on the leaf, usually on the underside, and with their long axis at right angles to the leaf surface; size, 1.3 by 0.35 mm. *The larva*: All black at hatching, later with pale markings, becoming more distinct after each successive molt. After the third molt the general color is dark purplish-black, with a median line of pale brick-red spots on the thorax and abdomen and also two lateral rows of similar spots. On segments 1 and 4 of the abdomen occur also two pale spots, one on either side of the median brick-colored spot and midway between it and the corresponding lateral spot. The full-grown larva has a length of 8 millimeters. *The pupa*: General color white, wing pads sienna brown. A large number of black spots and dashes are present but the prevailing color is white. Average size, 4 by 3.3 mm. *The adult*: Hemispherical, ashy-gray, with black markings, the elytra sometimes diffused with dull reddish blotches; head black, with central portion white or light gray; thorax (pronotum) black, with gray margins; elytra ashy-gray, with eight black spots on each elytron; legs yellow; abdomen reddish-yellow; average size, 5.2 by 4.2 mm. The adults of this species, if confined without food, will devour one another.

Table XIII indicates the predatory activities of two larvæ of *Adalia melanopleura* on walnut plant lice.

TABLE XIII.—*Adalia melanopleura*: Predatory activities on walnut plant lice, Walnut Creek, Cal., 1912.

Larva No.	Date of hatching.	Date of molt 1.	Number "lice" eaten to molt 1.	Date of molt 2.	Number "lice" eaten, molts 1 to 2.	Date of molt 3.	Number "lice" eaten, molts 2 to 3.	Date of pupation.	Total "lice" eaten.	Date of adult emergence.
1 2	Sept. 17 17	Sept. 20 19	41 35	Sept. 24 22	38 34	Sept. 26 25	30 33	Sept. 30 30	181 194	Oct. 12 12

In all, 375 plant lice were eaten in 26 days, or 14.4 per day per larva. The feeding period of both larvæ was 13 days as contrasted with an average of practically 18 days for the larvæ of the ashy-gray ladybird. *Adalia melanopleura* is considerably smaller than that species, its larva consuming in a period of 13 days half as many plant lice as the larva of the larger species will devour in 18 days. This larger species will consume 70 larvæ in a single day while the maggot of the large syrphid fly (*Catabomba pyrastri*) will dispose of over 100 and during the 23 days or so of its existence will devour over 1,000, or about 43.5 lice per day. However, in contrasting the two groups of predaceous insects—Syrphidæ and Coccinellidæ—it must be remembered that the former are aphidophagous only in the larval state

while both the adults and larvæ of ladybirds feed on plant lice. Mr. E. K. Carnes,¹ experimenting in the State Insectary at Sacramento, Cal., found that 20 adult beetles of *Hippodamia convergens* averaged 21.8 aphides per day and that the larvæ of this species each consumed from 250 to 300 plant lice during their larval existence. He found that adult females would deposit eggs for from a month to six weeks, laying on the average 15 eggs per day and feeding on the plant lice all the time. Essig² states that in the walnut orchards of Ventura County, Cal., *Olla abdominalis*, the ashy-gray ladybird, is by far the most beneficial insect in the natural control of the European walnut aphid (*Chromaphis juglandicola*).

ARTIFICIAL CONTROL OF WALNUT APHIDES.

The writer has been unable, save in one instance,³ to find any published account of artificial control tried or adopted for walnut plant-lice. Until the year 1910 no such work seems to have been performed along this line.⁴ In August of that year Mr. P. R. Jones, late of the Bureau of Entomology, carried out a series of laboratory experiments with a view to determining the efficiency of various washes against these aphides. A small hand pump was fitted with an Eddy-chamber nozzle and the applications made at a medium high pressure. Care was taken that not enough pressure was exerted to kill any of the "lice" by the force of the spray alone. Examinations were made 10 minutes after the applications. From these experiments the following results were obtained:

Commercial tobacco extract No. 2, containing 40 per cent nicotine, at strengths of 1-1,040 to 1-2,048, effective; dilutions weaker than 1-2,048, not effective.-

Commercial tobacco extract No. 1 containing about 4 per cent of nicotine at strength of 1-60, effective; dilutions weaker than 1-60, not effective (1-80 partially effective).

Commercial tobacco extract No. 1, at strengths varying from 1-60 to 1-200, combined with a 3 per cent distillate-oil emulsion, effective.

Commercial tobacco extract No. 2 at strengths varying from 1-1,000 to 1-2,650 combined with a 3 per cent distillate-oil emulsion, effective.

Commercial tobacco extract No. 1 at strengths varying from 1-60 to 1-200 combined with a 2 per cent distillate-oil emulsion, effective.

Commercial tobacco extract No. 2 at strengths varying from 1-1,000 to 1-2,620 combined with a 2 per cent distillate-oil emulsion, effective.

Distillate-oil emulsion at 2, 3, and 4 per cent strengths, effective.

Commercial lime-sulphur, 1-50, combined with commercial tobacco extract No. 1, 1-100, effective.

¹ Sept., 1912. Carnes, E. K. Insectary Division Reports for the months of June and July, 1912. Mo. Bul. Cal. State Hort. Com., v. 1, no. 10, p. 820-828.

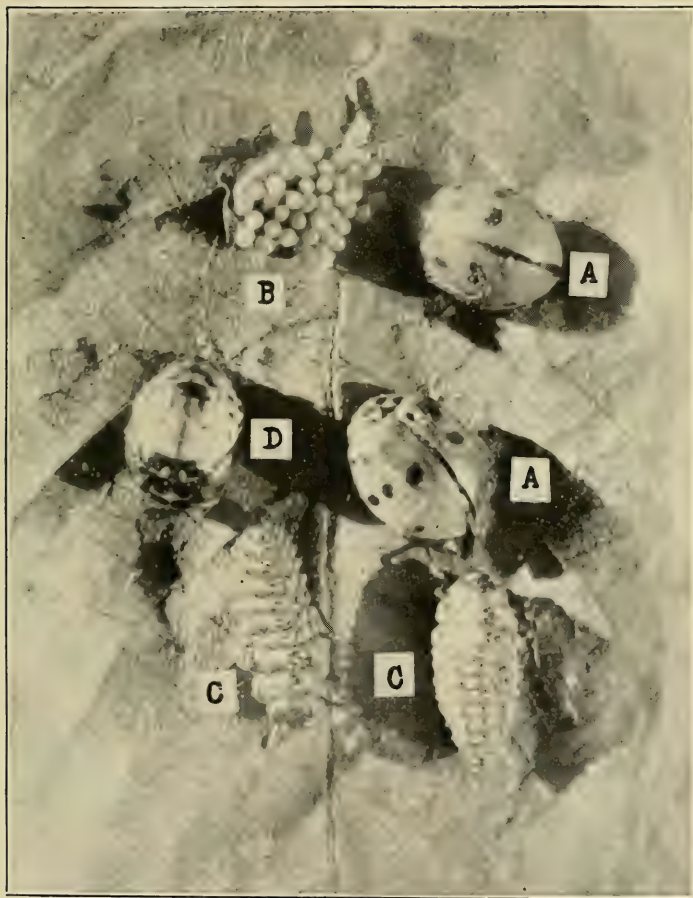
Some experiments with the common ladybird (*Hippodamia convergens*), p. 821-826.

² Apr., 1912. Essig, E. O. The walnut plant louse (*Chromaphis juglandicola* [Kalt] Walker). Mo. Bul. Cal. State Com. Hort., v. 1, no. 5, p. 190-194, figs. 72-73.

Control, p. 192.

³ Cf. Biennial Crop Pest and Hort. Report 1911-1912, Oregon Agr. Coll. Exp. Sta. Jan. 10, 1913, p. 165. "Blackleaf 40" and kerosene emulsion 10 per cent recommended.

⁴ Since going to press control experiments undertaken in the spring of 1913 in Southern California by the University of California have been published in Circular 107 of the Agricultural Experiment Station of the University of California.



THE ASHY-GRAY LADYBIRD (*OLLA ABDOMINALIS*).
[A, adult; B, eggs; C, larva; D, pupa. (After Essig.)]



FIG. 1.—TREE OF THE ROYAL HYBRID WALNUT IN GROVE OF MR. F. LEIB, SAN JOSE, CAL.



FIG. 2.—GENERAL VIEW OF WALNUT GROVE OF MR. F. LEIB, SAN JOSE, CAL.

Commercial lime-sulphur, 1-50, combined with commercial tobacco extract No. 1, 1-200, effective.

Commercial lime sulphur, 1-70, combined with commercial tobacco extract No. 2, 1-1,000, effective.

Commercial lime-sulphur 1-45, combined with commercial tobacco extract No. 2, 1-2,000, effective.

It is noticeable that the weaker solutions of tobacco extracts were not effective alone, but when combined with distillate-oil emulsion or lime-sulphur proved quite satisfactory. Possibly the most successful result was obtained with distillate-oil emulsion of only 2 per cent. Field experiments failed, however, to justify the use of this wash alone, for it proved to lack the killing power found in the tobacco-extract sprays. The emulsion serves, however, as a very good "spreader" for the nicotine killing agent, since it serves to distribute the spray over the leaf surface. Commercial tobacco extract No. 2 proved to have greater insecticidal value than commercial tobacco extract No. 1, judging by the corresponding strengths of the two sprays; and therefore in the field only the former was used. Foliage tests on an Eastern black walnut tree were made of all the washes used in the laboratory experiments, and in no case was any burning observed to result. This type of walnut seems more susceptible to burning injury than does the European or so-called "Persian" walnut.

FIELD EXPERIMENTS.

SPRING AND SUMMER TREATMENT.

Experiment No. 1.—Lime-sulphur (commercial 1-50) combined with commercial tobacco extract No. 2 (1-1,500). Orchard of Mr. I. Du Bois, San Jose, Cal. Two large European walnut trees badly infested with aphides were sprayed July 1, 1911, under an even pressure of 170 pounds. A count made on the following day showed that 95 per cent of the aphides had been destroyed by the wash.

Experiment No. 2.—Three per cent standard distillate-oil emulsion combined with commercial tobacco extract No. 2 (1-2,000). A large, badly infested European walnut tree in the yard of the experiment station at San Jose was treated, July 3, 1911, with this spray at an even pressure of 170 pounds. A count made July 5 showed that over 95 per cent of the aphides had been killed.

Experiment No. 3.—Commercial tobacco extract No. 2 (1-1,500). Orchard of Mr. F. Leib, near San Jose, Cal. (Pl. IV, figs. 1, 2). A block of 10 walnut trees badly infested was sprayed, May 21, 1912, under a pressure fluctuating from 60 to 140 pounds. A count made two days later showed that not over 40 per cent of the "lice" were destroyed.

Experiment No. 4.—Commercial tobacco extract No. 2 (1-1,500) combined with 2 per cent homemade distillate-oil emulsion. Orchard of Mr. F. Leib, near San Jose, Cal. A block of 10 badly infested walnut trees was sprayed, May 21, 1912, under pressure similar to that of experiment No. 3. A count made two days later showed that 98 per cent of the insects had succumbed. Some oil burning appeared on the foliage and nuts owing to insufficient agitation in the preparation of the emulsion and consequent freeing of oil.

Experiments Nos. 3 and 4 were made to determine whether the tobacco extract alone would prove effective in the field. Results indicate that a weak solution of oil emulsion is necessary to act as a "spreader" for the tobacco.

Experiment No. 5.—Distillate-oil emulsion, 2 per cent. Orchard of Mr. F. Leib, near San Jose, Cal. A block of six badly infested walnut trees was sprayed under 110 pounds pressure, July 31, 1912. A count made on August 6 showed that 74 per cent of the "lice" had been destroyed.

Experiment No. 6.—Distillate-oil emulsion, 2 per cent, combined with commercial tobacco extract No. 2 (1-2,000). Orchard of Mr. F. Leib, near San Jose, Cal. (Pl. IV, figs. 1, 2). Six walnut trees, badly infested, were sprayed under a pressure of 110 pounds. A count, made August 6, showed that 85 per cent of the "lice" had been killed by the spray.

Experiment No. 7.—Whale-oil soap, 1 pound; water, 5 gallons. Orchard of Mr. E. I. Hutchinson, Concord, Cal. A block of 12 moderately infested European walnut trees was sprayed under 150 pounds pressure, May 10, 1913. A count made two days later showed that out of 473 "lice" counted, 263, or 55.6 per cent, had been destroyed. A thorough drenching had been applied and the trees were in full leaf. It was noticed that the great majority of the "lice" that escaped were situated close to the base of the midrib. In this position they were partly protected by the projecting rib, and it is to be supposed that the wash lacked the pressure necessary to reach these individuals.

All the foregoing experiments were undertaken on trees on which the foliage was fully developed. It was noticeable that on thickly foliated trees the percentage of plant lice killed was the smallest, while on thinly foliated trees the greatest mortality resulted. Much of the leaf surface on thickly foliated trees is almost inaccessible to spray.

A comparison of the results of the foregoing tests favors distillate-oil emulsion and tobacco. The most desirable combination for spring and summer spraying is a 2 per cent distillate-oil emulsion, commercial or homemade, combined with commercial tobacco extract No. 2, 1 to 1,500. High pressure (150 pounds or over) is desirable, although not absolutely necessary unless the spraying be done before the walnut leaflets have flattened out in spring.

In timing the application for the aphides on the leaves it is desirable to spray as early as possible in order to reduce the amount of leaf surface to be covered by the wash and to destroy the plant lice before they attack the nuts. On the other hand it will be found very hard to destroy the plant lice before the leaflets flatten out, for the young leaflets are pressed against one another in a manner that affords very good protection to the insects from a spray. Moreover at this period all the stem-mother plant lice will not have hatched from the winter eggs. The time most preferable for the application is just as soon as the growing leaflets shall have flattened out and before they have attained their full size. At this time the "lice" have all hatched and are all exposed on the underside of the leaves. Should an oil spray be applied care should be taken that there is no free oil in the emulsion, as the young nuts are susceptible to burning. No stronger than a 2 per cent distillate-oil emulsion should be used for this early application. The spray should be directed to the underside of the leaves, and angle nozzles used. A round nozzle is to be pre-

ferred to one of the Clipper type, as the former will diffuse the spray better over the leaf surface. Such a driving-spray nozzle as that devised by the Massachusetts Agricultural College is desirable for spraying trees of large size. If there are unsprayed walnut trees in the vicinity it may be necessary to make a second application some two or three weeks later, as plant lice are apt to have migrated from these to the sprayed trees.

On account of the extended period over which the sexual forms are produced, fall spraying for these forms, unless repeated again and again, will be of little value.

It should be borne in mind that the number of "lice" hatching in the spring from the winter eggs varies considerably year by year in a given locality or orchard and also that the hatching time of these "lice" is regulated by the sap flow in that particular tree upon which the eggs happened to be placed. The hatching of the winter eggs is not regulated by temperature conditions. Hence the stage in the seasonal development of the aphidids corresponds to the stage in development of that particular tree on which the stem-mother lice were produced, leaving out of consideration the possibility of migrants arriving from other trees. This point is of importance when it is considered that the different varieties of cultivated walnuts put out their leaves and produce their nuts at different times and that these functions are performed by individual varieties at different times dependent on locality and seasonal meteorological conditions.

Table XIV summarizes the control experiments made for spring and summer treatment.

TABLE XIV.—*Summary of spring and summer spraying experiments against walnut aphides, San Jose and Walnut Creek, Cal., 1911, 1912, and 1913.*

Character of spray.	Date of application.	Number trees sprayed.	Result of spray; per cent of plant lice killed.	Cost per diluted gallon.
Commercial lime-sulphur, 1-50 and commercial tobacco extract No. 2 (1-1,500).....	July 1, 1911	2	95	\$.012
3 per cent distillate-oil emulsion (homemade) and commercial tobacco extract No. 2 (1-2,000).....	July 3, 1911	1	95	.0088
Commercial tobacco extract No. 2 (1-1,500).....	May 21, 1912	10	40	.008
2 per cent distillate-oil emulsion (homemade) and commercial tobacco extract No. 2 (1-1,500).....	do.....	10	98	.0098
2 per cent distillate-oil emulsion (commercial).....	July 31, 1912	6	74	.0067
2 per cent distillate-oil emulsion (commercial) and commercial tobacco extract No. 2 (1-2,000).....	do.....	6	85	.0127
Whale-oil soap (homemade), 1 pound to 5 gallons water..	May 10, 1913	12	55.6	.004

WINTER TREATMENT.

Experiment No. 1.—Crude-oil emulsion, 12 per cent (crude oil, 27° Baumé). Orchard of Mr. George Whitman, Concord, Cal. A block of 31 European walnut trees of moderate size were sprayed February 25, 1913, under a pressure of from 150 to 175 pounds. Three gallons of spray were applied to each tree and "Friend" nozzles used. The trees were well drenched. Examination made April 5, 1913, showed that trees were starting to leaf. Most of the leaves were as yet tightly closed, but the basal leaves of many

shoots were opened. A general survey of the sprayed block and of a check unsprayed block indicated equal infestation by young stem mothers. Plant lice were not all hatched. An examination made April 15, 1913, showed that trees were well out in leaf. All stem mothers had hatched. A general survey of sprayed and unsprayed trees showed no apparent difference in infestation. A count of 28 leaf clusters selected at random from the sprayed trees yielded 21 stem mothers, while a similar count of the same number of leaf clusters from unsprayed trees yielded 29 stem mothers. It may be inferred from this experiment that the crude-oil emulsion destroyed few, if any, of the winter eggs.

Experiment No. 2.—Commercial lime-sulphur, 1-10. (Concentrated solution, 33° Baumé.) Orchard of Mr. George Whitman, Concord, Cal. A block of four large trees of the European walnut were sprayed March 5, 1913, under a pressure of 100 pounds. About 14 gallons of spray were applied to each tree and "Friend" angle nozzles used. Eggs were abundant on both sprayed and check trees. The leaf buds on these trees began to open April 1, 1913. Examination was made April 15, 1913. Trees were then well out in leaf. The stem mothers were all hatched. The lime had no effect in retarding leafing. A count of 20 leaf clusters taken at random on the sprayed block yielded no plant lice, while a similar count of the same number of leaves on the check trees yielded 27 stem mothers. Further examination showed that on the sprayed trees no plant lice could be found, while on the check trees nearly every leaf cluster had one or more of the insects.

A subsidiary experiment was undertaken on two young California black walnut trees, both infested with eggs. One of these trees was treated with commercial lime-sulphur, 1-9 (concentrated solution 33° Baumé), and the other left as a check. On the sprayed tree no eggs hatched and when examined on April 17, 1913, the eggs were shrunk and distorted, the embryos having been destroyed within the eggshell. The eggs on the check tree hatched normally about the end of March.

Experiment No. 3.—Crude-oil emulsion, lime-sulphur, and "Yel-ros." Vrooman orchard, Santa Rosa, Cal. Four plats were sprayed, April 9-11, 1913, with a power outfit at high pressure, as follows: Plat 1, 40 trees, crude oil (22° Baumé) emulsion, 8 per cent; plat 2, 40 trees, lime-sulphur, 1 to 8; plat 3, "Yel-ros," 1 to 25, 16 trees; plat 4, "Yel-ros," 1 to 40, 24 trees. These applications were made on late Franquette walnuts, dormant at the time of spraying. The orchard was well infested with the winter eggs of the plant lice. An examination, May 27, 1913, showed that the trees were well out in leaf. Stem mother plant lice were mostly about two-thirds grown. Counts of 80 leaves (about 480 leaflets) taken at random from each of the four plats and from a check unsprayed plat resulted as follows:

TABLE XV.—*Winter spraying experiment No. 3 against walnut aphides, Vrooman orchard, Santa Rosa, Cal., 1913.*

Plat.	Number of "lice" on 80 leaves.	Per cent of number on check.
Crude-oil emulsion, 8 per cent.....	11	10.6
Lime-sulphur, 1 to 8.....	2	1.9
"Yel-ros," 1 to 25.....	14	13.4
"Yel-ros," 1 to 40.....	97	93.2
Check—unsprayed.....	104	100.0

The best results, therefore, were obtained by the lime-sulphur wash. The greater efficiency of the 8 per cent crude-oil emulsion over the 12 per cent crude oil used in experiment No. 1 is probably due to the heavier grade of oil (22° Baumé) used in the 8 per cent experiment. The heavier oil remains longer on the trees and coats the eggs of the aphides more satisfactorily than the oil of lighter grade. As may be seen from Table XVI both the 8 per cent crude-oil emulsion and "Yel-ros," 1 to 25, gave good results, but "Yel-ros," 1 to 40, was quite ineffective. Table XVI is a summary of experiments against the winter eggs:

TABLE XVI.—*Summary of experiments on the winter eggs, Walnut Creek and Santa Rosa, Cal., 1913.*

Character of spray.	Date of application.	Number of trees sprayed.	Date of examination.	Plant lice present (check—100).	Cost per diluted gallon.
				<i>Per cent.</i>	
Crude-oil (27° Baumé) emulsion, 12 per cent.	Feb. 25....	31	Apr. 5, 15..	72.4	\$0.01
Commercial lime-sulphur, 1 to 10.....	Mar. 5....	4	do	.0	.02
Crude-oil (22° Baumé) emulsion, 8 per cent.	Apr. 9-11..	40	May 27....	10.6	.0073
Commercial lime-sulphur, 1 to 8.....	do	40	do	1.9	.025
"Yel-ros," 1 to 25.....	do	16	do	13.4	.028
"Yel-ros," 1 to 40.....	do	24	do	93.2	.0175

It is in a measure unfortunate that the homemade 1-2-1 lime-sulphur spray was not tried. This is considerably cheaper than the commercial article, but there is no reason to suppose that the winter formula of the homemade lime-sulphur would not prove quite effective judging by the results obtained with commercial lime-sulphur.

In recommending winter sprays for the plant lice infesting walnut trees the writer must accord the preference to lime-sulphur, 1-8 to 1-11, while good work may be expected from crude-oil emulsion, 8 to 12 per cent, using the heavier grades of oil (not lighter than 24° Baumé), and from "Yel-ros," 1-25. The oil emulsion (homemade) is the cheapest winter spray, although there is little difference between its cost and that of the homemade lime-sulphur wash, winter formula.

In applying the spray for the aphid eggs the wash should be directed so as to cover completely every part of the twigs and limbs. Late spraying, i. e., making the application just before the buds are beginning to swell, is preferable to spraying earlier, especially if crude-oil emulsion is used, as the oil does its best work soon after it is applied and the plant lice at hatching time are more easily destroyed by it.

In concluding the section on artificial control the author would like to express his thanks to Mr. Frank Leib, San Jose, Cal., and Messrs. George Whitman and E. I. Hutchinson, Concord, Cal., for their help and cooperation in the carrying out of field experiments on their orchards, and also to Balfour, Guthrie & Co., San Francisco, Cal., by whose courtesy the Santa Rosa experiments were made possible, they having made the spray applications under the author's supervision.

SUMMARY.

The life history of walnut aphides in California is briefly as follows: A week or so before the buds open on the trees in the spring the aphidids begin to hatch from the winter eggs. As soon as the young foliage appears the "lice" settle on it, and after feeding for a month or so become adults. These stem mothers are always winged and like plant lice of later generations are capable of migrating to other trees and orchards. As soon as they are fully developed they produce young parthenogenetically. These second-generation young become mature in three weeks and in turn produce young. The individuals of the third and subsequent generations of summer mature in about 16 days. On early-leafing varieties there are 10 or 11 viviparous generations in the year while on late varieties there are 8 or 9. The production of the sexual generation is prolonged over four months, these forms first appearing in July. After the sexes (comprised of the winged male and the wingless female) mate, the female repairs to the twigs and limbs of the tree, there to deposit her eggs. Winter is passed in the egg stage only.

In general the aphidids inhabit the underside of the leaves, but those of the second, third, and fourth generations often attack the nuts, sometimes seriously dwarfing them (see Pl. I, fig. 1). Occasionally the "lice" will be found on the upper surface of the leaf. When infestation on the leaves and nuts is severe the vitality of the infested tree is impaired. The aphidids excrete a sweet, gummy, transparent substance much sought after by ants, and in this thrives a black sooty fungus. This black fungus often covers the upper sides of the lower leaves and the upper part of the nuts, thereby interfering with the respiratory action of the plant tissues.

Walnut plant lice have many natural foes, all predatory. These serve to keep the aphidids in check but do not appear in sufficient numbers until after the "lice" have had time to injure the nuts. The most persistent of them is the ashy-gray ladybird beetle (*Olla abdominalis* Say).

Aphidids on walnuts can be controlled artificially with sprays. The winter spraying directed against the eggs is the easier to apply, and high trees can be reached by a winter wash with ease, whereas in the spring and summer so thick is the foliage that a thorough application is hard to accomplish satisfactorily. Furthermore, far less material is required when the trees are bare. Lime-sulphur and crude-oil emulsions are effective, especially the first named. The spray should be directed all over limbs and twigs so as to cover every part. If it is necessary to spray in spring or summer, a combination of 2 per cent distillate-oil emulsion and commercial tobacco extract No. 2 (1 to 1,500) will prove effective provided it be applied under a pressure of at least 150 pounds and the spray directed on the nuts and underside of the leaves.

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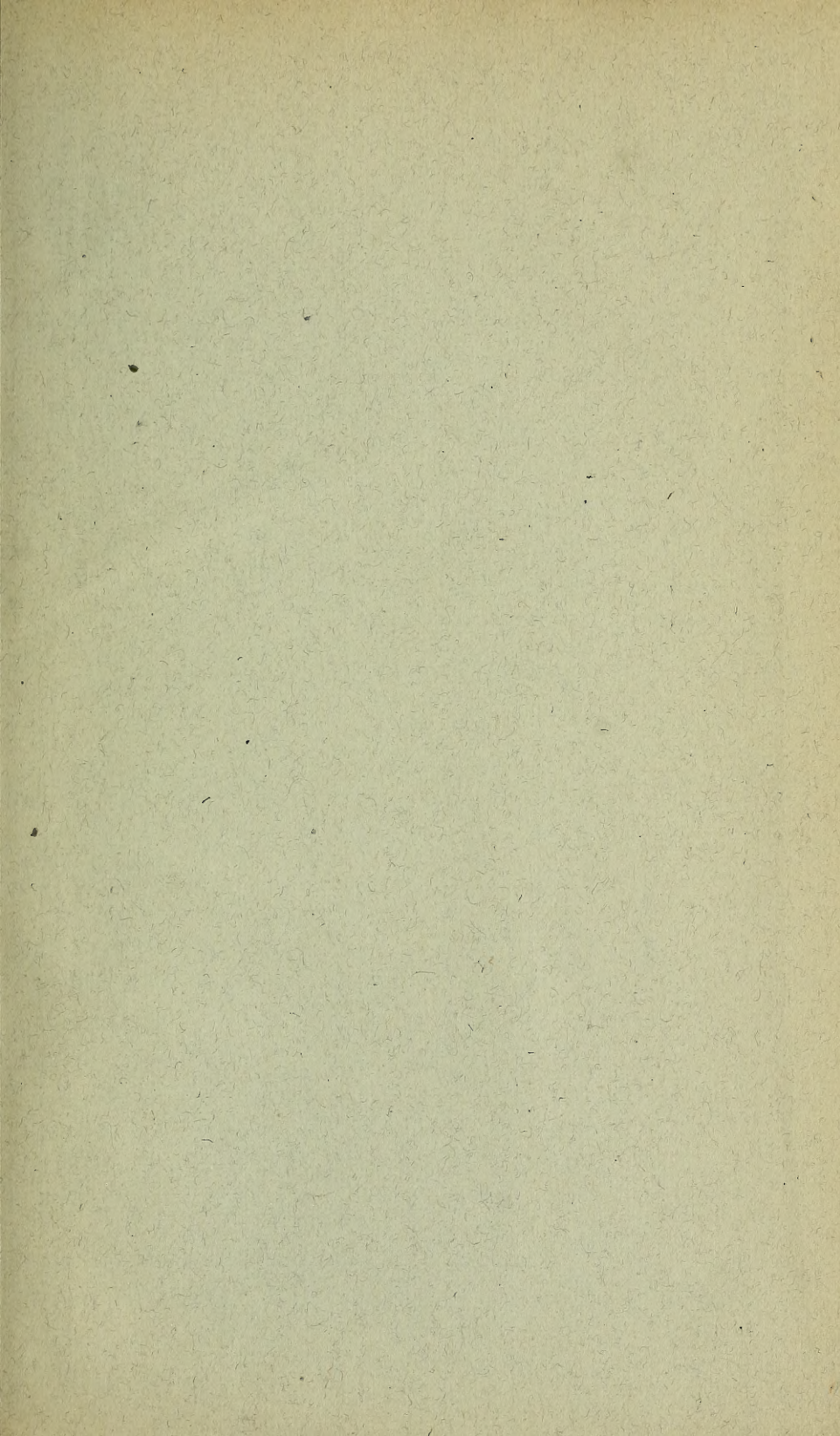
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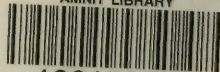
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